SUDBURY ENVIRONMENTAL STUDY

PRECIPITATION QUALITY AND WET DEPOSITION IN THE SUDBURY BASIN: SUDBURY ENVIRONMENTAL STUDY CUMULATIVE PRECIPITATION NETWORK RESULTS.

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Ministry of the Environment
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Minister

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Deputy Minister

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by

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SYNOPSIS

This report describes the results of a study into the effect of smelting activities on the long-term wet deposition field in the Sudbury area. A companion report[1] presents a more detailed assessment of smelter contributions, based on the Sudbury Environmental Study event precipitation monitoring network.

During the period June 1978 - May 1980, about 20 wet-only deposition monitors were operated within a 150 Km radius of Sudbury. The samples were collected over a monthly period, and were analysed for concentrations of acids, acid-related ions (sulfates, nitrates, ammonium, calcium, magnesium), a number of trace metals (copper, nickel, zinc, iron, lead, chromium and cadmium), and other substances (aluminum, potassium, sodium, chloride, fluoride). Statistical analyses were carried out on the data. Concentration and deposition fields were constructed for the above substances, and assessed in the light of concurrent smelter operations. It is of special interest that the larger of the two smelters, operated by INCO Limited which emits sulfur and most of the trace metals at a rate typically more than ten times that of Falconbridge) was not operating, either due to maintenance or vacation shutdowns or labor disputes, during most of the first year discussed in this report (most days during July 1978 to May 1979). Thus much of the discussion on smelter impact involves a comparison of the two periods June 1978 - May 1979 and June 1979 -May 1980.

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1. Air Resources Branch Report ARB-05-82-ARSP, "An Analysis of the Impact of Smelter Emissions on Precipitation Quality and Wet Deposition in the Sudbury Area: Sudbury Environmental Study Event Precipitation Network Results".

During the monitoring period, the observed pH values ranged from 3.5 to 5.4, with a geometric mean of 4.1 for the entire network. The corresponding ranges (and geometric means) for concentrations of some other substances of interest, in mg l^{-1}, were: sulfate, 18.0 - 0.3 (3.49); nitrate (as nitrogen), 3.0 - 0.2 (0.60); ammonium (as nitrogen), 3.1 - 0.01 (0.34); iron, 1.4 - 0.006 (0.068); copper, 1.1 - detection limit (d.l.) (0.003); nickel, 0.079 -d.l. (0.002); lead, 0.067 - d.l. (0.011); and zinc, 0.31 - 0.001 (0.010).

A comparison of the geometric means of the 78/79 and 79/80 periods referred to above, of all stations, gave : pH, 4.1 (78/79) and 4.2 (79/80); and in mg l^{-1} sulfate, 3.4 and 3.4; N-nitrate, 0.6 and 0.6; N-ammonium, 0.3 and 0.4; Fe, 0.06 and 0.07; Cu, 0.003 and 0.004; Ni, 0.001 and 0.002; Pb, 0.013 and 0.009; and Zn, 0.011 and 0.009. These results suggest the importance of sources other than the local ones, e.g. long range transport in view of the fact that an extensive shutdown/strike took place in the 78/79 period.

The precipitation concentration and wet deposition fields for the June, 1978 to May, 1979 and June, 1979 to May, 1980 periods showed the greatest impact of smelting activities to be for copper and nickel. A second group of trace metals (lead, zinc, chromium and cadmium) showed only a small detectable smelter impact. Results for the other substances examined ($SO^{=}_{4}$, NO^{-}_{3}, NH^{+}_{4}, Fe, Al, Mg^{++}, Ca^{++}, K^{+}, Na^{+} and Cl^{-}) apparently were largely governed by non-smelter-related phenomena, such as long-range transport into the study area, and contributions of local wind-blown dust or vehicular traffic. These results are in agreement with an independent analysis of the event network data[1], which suggest that the smelter contribution to the wet deposition of substances other than Cu and Ni is generally less than 20% of the total in the Sudbury basin, and

for these substances, any increment due to smelting activities is evidently masked by the inherent "noise" in the long-term data (due to precipitation variability, sampling and analytical errors, contributions from local non-smelter sources and long-range transport, etc).

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1. INTRODUCTION

As part of the Sudbury Environmental Study (SES), two precipitation networks, a cumulative wet-depostiion network, and an event deposition network, were commissioned, to examine the fate of the atmospheric pollutants emitted by the local smelters via the pathway of wet depostion, and the contributions of the local smelter sources to the precipitation quality and wet deposition fields in the Sudbury basin.

In this report, discussion will be focussed solely on the cumulative network. In the following section, a brief historical development of the Air Resources Branch's involvement in precipitation monitoring will be given, together with a description of the cumulative network, including sampling and analytical methodologies. This will be followed by a general statistical profile of the network results. Finally, the long term precipitation concentration and deposition patterns in the greater Sudbury area will be discussed for the study period.

A companion volume of appendices referred to in this report, containing all the individual data values and detailed results which are too voluminous to be included here, is available from the Air Resources Branch upon request.

2. THE NETWORK

2.1 History of the ARB Precipitation Monitoring Program

The Air Resources Branch first became involved in precipitation monitoring in the Sudbury area in the early seventies. This early participitation consisted of providing funding for the operation of a comprehensive bulk deposition network from 1972 to 1976. The network was designed and managed by Professor J.R. Kramer of McMaster University in Hamilton, Ontario, and the results of this work have been presented elsewhere (1-3).

In 1976, the state-of-the-art in precipitation chemistry monitoring had advanced to a point where long - term bulk deposition sampling was considered unsatisfactory for measuring wet-only deposition. The bulk deposition network was therefore terminated and plans were made to install a wet-only deposition monitoring network as part of the Sudbury Environmental Study. The initial installations of monthly wet-only sampling stations took place in the summer and fall of 1977 and operation began in December 1977. The full implementation of the network was completed in mid-1978. The network was designed to monitor the long term wet deposition field within 150 Km of Sudbury. It was called the Sudbury Environmental Study Cumulative Precipitation Monitoring Network because precipitation was accumulated for a month.

In June 1978, a second deposition monitoring network was installed and began operation. The sampling protocol in this network differed from that of the Cumulative Network in that it measured daily bulk deposition on days of

precipitation, rather than monthly wet-only deposition. Since most of the samples which were collected on a daily basis corresponded to precipitation events, the network was called the Sudbury Environmental Study Event Precipitation Monitoring Network. Its objective was to determine the relative contribution of Sudbury emissions to the wet deposition field in the Sudbury area under various meteorological conditions . To fulfill this objective, the design of the Event Network was necessarily different from that of the Cumulative Network, i.e. sampling stations were predominantly located within 40 Km of the Sudbury smelters. Details of this network are given elsewhere (4).

Both sampling studies continued operation until the end of the Sudbury Environmental Study field program in May, 1980. Seven of the original Cumulative Network stations were retained after that time and became sites for the Province of Ontario's Acidic Precipitation in Ontario Study (APIOS) Cumulative Precipitation Monitoring Network (5). All other stations were disbanded.

2.2 Objectives

The objectives of the SES Cumulative Network were two-fold:

1. To determine the impact of the local smelter sources on the long term wet deposition pattern of selected chemical species in the Sudbury area.

2. To provide wet deposition data for the development and verification of mathematical models of precipitation scavenging in the Sudbury area.

2.3 Design and Operation

Over the two-and-half year network operation, twenty-two stations were installed within a 150 Km radius of Sudbury. Figure 1 is a map of the network stations. At eighteen sites, Sangamo wet-only samplers (Figure 2) were used. At four remote sites (Halfway Lake, Florence Lake, Graveyard Lake and Chiniguchi Lake), where line power was not easily accessable, battery-operated Aerochem Metrics Samplers (Figure 3) were used. The two samplers differed in collection areas; being 304 cm^2 and 647 cm^2 respectively. Under severe winter sampling conditions, the Aerochem Metrics sampler sensors did not respond as well as those of the Sangamo type and this fact is reflected in the number of useful samples collected. Modifications to the sensor of the Sangamo sampler sensor were made at several stages during the network operation to further improve the collection efficiency, as it was the primary equipment used. It is felt that data from the first half year's operation (from Dec, 1977 to May, 1978) should be used with reservation due to below average collection efficiencies. In general, collection efficiency was higher in summer than that in winter.

Station names and coordinates are given in Table 1. The positions relative to the INCO source are shown in Table 2. At each of the sites, there was a storage gauge (Figure 4) for precipitation depth measurement. At some selected sites, there were also Fisher and Porter (Figure 5) rain gauges.

The cumulative precipitation samples were collected at the end of each month ($\pm$ 3 days) by Sudbury Environmental Study field personnel. If sufficient volume was available, a field pH measurement was made before transporting the samples to the Laboratory Services Branch of the Ontario Ministry of the Environment in Toronto for further chemical analysis.

During most of the network's lifetime, the acid-related parameters were analyzed primarily with pH meter, titration, and ion chromatography techniques. Trace metals were measured by Atomic Absorption Spectroscopy. A summary of the analytical methods used is given in Table 3.

A summary of the overall performance of the network is given in Table 4. Both the operating periods and the number of missing samples (i.e. where the sampler did not operate, or obvious contamination led to data rejection) are given for each site. Note that during the period July - September 1978, INCO and Falconbridge were shut down for maintenance or due to vacation - see Table 5. During this period, samples were collected on a semi-monthly basis (hence the double entries in Table 4). Detailed descriptions of network design, siting criteria, instrumentation, chemical analysis methods and network performance are given in Appendix 1.

strong acids were found to account for over 70% of the total acid content of the precipitation samples.

A wide range of concentrations for the smelter-related trace metals was observed. Maximum and minimum values (mg l^{-1}) for some of these are : Fe = 1.43, 0.006; Cu = 1.07, less than detection limit (0.001); Ni = 0.079, less than detection limit (0.001); Pb = 0.067, less than detection limit (0.001); and Zn = 0.31, 0.001. The geometric mean values (mg l^{-1}) are: Fe = 0.068; Cu = 0.003; Ni = 0.002; Pb = 0.011 and Zn = 0.010.

Table 7 gives the individual station data for pH, SO_4 and NO_3. It is of interest to note that the ratio of mean concentrations of SO_4 to N-NO_3 varies from site to site. Details of all other species are given in Section 3 of the Supplementary Volume.

A statistical analysis of the data for the two periods, i.e. June, 1978 to May, 1979 and June 1979 to May, 1980 yields the results shown in Tables 8 and 9. During the first period, atypical smelter operations were experienced both at INCO and Falconbridge due to maintenance/vacation shutdowns and strikes. This is especially significant in the case of the former source. Therefore a direct comparison of the statistics of these two periods should shed some light on the potential impact due to the local sources.

A comparison of the geometric means for all stations of the 78/79 and 79/80 periods referred to above, gave: pH, 4.1 (78/79) and 4.2 (79/80); and in mg l^{-1}: sulfate, 3.4 and 3.4; N-nitrate, 0.6 and 0.6; N-ammonium, 0.3 and 0.4; Fe, 0.06 and 0.07; Cu, 0.003 and 0.004; Ni, 0.001 and 0.002; Pb, 0.013 and 0.009; and Zn, 0.011 and 0.009. It is noted that except for the trace metals which are

primarily smelter-originated and which are in the coarse particle size range, all other parameters had lower or equal concentration values during the operating period as compared to those of the shutdown period, suggesting the importance of precipitation variability and transport from sources outside the immediate vicinity of the study area. All the parameters belonging to the latter group have either gaseous precursors or are in the fine-particle size range and therefore have a long atmospheric residence times and are prone to long range transport.

3.2 Correlation and Regression Analyses

Table 10 summarizes the linear correlation coefficients between parameter pairs which are statistically significant at the 99% confidence level. All data from all stations over the 2½ years were included in the computation.

As expected, there is an inverse dependence of precipitation concentration on sample volume, but the low correlation coefficients indicate that the relationship may not be strictly linear. All the acid-related parameters, H_f, H_t, SO_4, NO_3 and NH_4 show significant correlations. H_f is strongly correlated with H_t, and is correlated better with SO_4 than with NO_3. The correlations between NH_4 and SO_4, as well as NH_4 and NO_3, suggest that these species might be chemically associated. The very high correlation between Na and Cl is probably due to the use of road salt in the Sudbury area during the winter. Some of the other major metallic ions (Ca and Mg) show significant correlations reflecting their common soil origin. The smelter trace metals are in general significantly correlated, with few exceptions. Correlation tables for individual stations are shown in Section 3 of the Supplementary Volume.

Relating the concentration (in mg l^{-1}) parameters Y in terms of X in

a linear fashion, ($Y = \underline{A} + \underline{B}X$), gave the regression coefficients A and B which are tabulated as the top and lower values respectively of each entry in Table 11 for all the stations data. The corresponding results for individual stations are given in Section 4 of the Supplementary Volume.

3.3 Intersite Correlation

Intersite correlation of the concentration of various parameters are given in Section 5 of the Supplementary Volume. Only significant correlations (at 99% confidence level) are tabulated.

Comparisons of observations at different network sites should shed some light on the nature of pollution, whether it is associated with long range transport or due to local sources. Due to time constraints, this will not be addressed in this report.

4. LONG TERM WET DEPOSITION PATTERN IN THE SUDBURY AREA

As indicated earlier, during the first half year of network operation, there were only 10 stations, and moreover instrumentation problems due to sensor sensitivity were encountered. Therefore, in the rest of the report, data for only the last two years' operation (June 1978 - May, 1980) will be used in the study of the wet deposition pattern.

It was noted earlier that during 1978 and 1979, both INCO and Falconbridge experienced atypical operational conditions due to maintenance and vacation shutdowns and strikes. These conditions are summarized in Table 5. It is of interest to examine whether there was any concurrent observable change in the deposition pattern.

Both concentration and deposition pattern will be examined. In the discussion below, the summer season is defined as June - August; autumn as September - November; winter as December - February; and spring as March - May. Each annual average includes the period June - May.

It should be noted that the computer-generated contour diagrams for concentration and deposition, to be discussed below, contain considerably more detail than is justified by the data, especially around the periphery of the sampling area. Therefore, the approach has been taken of presenting the complete product of the computer objective analysis, while highlighting what are considered to be the significant features of the contour diagrams.

4.1 Concentration Data

The seasonal volume-weighted concentration averages of the various

parameters for all stations are shown in Section 6 of the Supplementary Volume. The corresponding annual averages are shown in Table 12.

Most of the parameters do not exhibit temporal variation. However of particular relevance to the acidity in rain, there are 3 parameters that should be examined, i.e. SO_4, NO_3 and NH_4, SO_4 concentration peaks during the summer time, whereas for the other two species, less obvious seasonal variation is observed. The summer peak in SO_4 may be a result of different source origins, different oxidation rates and different scavenging characteristics associated with the summer and winter periods. However, this fact also has profound implications for control strategies and effects on the ecosystems due to the change of NO_3 to SO_4 concentration ratios and their relative contributions to precipitation acidity.

4.2 Deposition Data

From May to October, when precipitation corresponded primarily to rain, collection efficiency was near 100% and the precipitation depth as measured in the sampler was used in the deposition calculations. For the period from November to April, when snow is the predominant form of precipitation, the collection efficiency was observed to be low and variable. Therefore, precipitation depth, as determined by interpolation (6) from Environment Canada's network of climatological stations in the Sudbury area were calculated. Standard precipitation amount measurements are made using a standard rain gauge in summer and a Nipher-shielded snow gauge in winter. The same interpolation procedures were used when data were missing in the summer months.

Deposition (mass per unit area per unit time) is the product of concentration and precipitation depth. For those months with no actual concentration data because of no sample collected, the average annual concentrations as given in Table 12 were used instead. These monthly precipitation depth data, as well as the corresponding deposition values, are summarized in Section 7 of the Supplementary Volume.

Once the monthly deposition values were determined, they were used to calculate geometric means for the seasons and years of interest. During the summer of 1978, semi-monthly samples were collected to match the smelter operating conditions. These semi-monthly results were combined to form composite monthly values before the geometric means were obtained. The yearly data are given in Table 13 and the seasonal data in Section 8 of the Supplementary Volume.

4.3 Contours of Annual Concentration and Deposition

Using the interpolation/contour program, data from Tables 12 and 13 were plotted to yield concentration and deposition isopleth maps for the various measured parameters in the greater Sudbury area.

Concentration and deposition estimates given in Tables 12 and 13 are monthly averages calculated over annual intervals of June 78 to May 79 and June 79 to May 80. The former were calculated using volume-weighted averages. The latter are geometric mean values. Because of missing data in some sampling periods, these tabulated values may correspond only to a small set of original monthly data, and therefore may not be truly representative of the entire year. Therefore, in the contour calculations, only average values corresponding to

stations with at least 7 out of the 12 month data were used. Those which were not used are underlined. Also, a closer inspection of the data shows that some averages are anomalously high due to one or two samples. Provided that there was evidence to indicate that these results were not representative of the station (e.g. by looking at soil-related parameters), they were eliminated and new averages (without these suspected values which corresponded to less than 0.3% of the total data) calculated for contour plotting.

A good portion of the first period (June '78 - May '79) corresponded to INCO's strike period (see Table 5) and therefore a comparison of the two years' contours may shed some light on the influence of the INCO smelter operation on local precipitation. However, it should be emphasized that the comparison is not straightforward due to year-to-year meteorological variations. This is especially important to bear in mind when interpreting results of parameters associated with long range transport, e.g. SO_4, NO_3, NH_4 etc.

It should be pointed out that for a number of reasons the network density - especially in areas close to the smelters - was not as high as may have been wished. Because of this, some of the details in the concentration/deposition field may have been missed in the figures to be discussed.

4.3.1 Concentration Data

In the following discussion, we will focus on the locations and the relative magnitude of the maximum and minimum values in the monthly concentration field over a year, and the relative magnitude of the observed data in the two years. By so doing, we can define the long term pattern and estimate the influence of local sources on the long-term precipitation quality.

Figures 6 and 7 correspond to the Sudbury airport (ground level) and MOE meteorological tower (114 m level) precipitation windroses for the two study years. Both the lower and upper windroses together with the combined windrose are presented. It is of interest to note that the wind roses for the two years are quite similar with prevalent winds from the S and SW sectors for the combined precipitation wind rose.

Figures 8 to 26 give the concentration fields generated by the interpolation/contour programs for each parameter. The results are best interpreted in terms of the nature of the pollutants. The pollutants monitored can be grouped into eight different categories.

- H_f (Figures 8a and 8b): the maximum H_f concentrations are in the general areas of Burwash and Lively during both periods, and there is somewhat less than a two-fold variation across the network. Especially in the 78/79 data, the maximum concentrations fell roughly along the S-N and SW-NE axes, corresponding to dominant precipitation wind rose directions, and suggesting a local source influence on the long-term precipitation acidity field. However, the fact that the 78/79 H_f values (when the INCO smelter was largely shut down) were higher than those in the 79/80 period which showed local influence better, suggests a significant contribution of long-range transport.

- H_t (Figures 9a and 9b): a weak smelter influence can be observed in the total acidity data during the 79/80 period. There is a concentration gradient from S to N in the 78/79 data. As with H_f, values are in general higher during the 78/79 shutdown period.

- SO_4 (Figures 10a and 10b): the distribution of sulfate concentrations is very similar to that of H_f for both years, indicating that SO_4 is an important contributor to free acidity. During the 79/80 period, there is a maximum along the SE-NW axis, probably due to smelting acitivities but, as with H_f, the somewhat higher background SO_4 values during the shutdown, as compared to the operating period, show the importance of long-range transport in this area.

- NO_3 (Figures 11a and 11b): source testing studies have shown that the amounts of nitrogen oxides produced by the Sudbury smelters are small (7). Thus the concentration field observed in the figures is mainly due to other sources, the general decrease from south to north suggesting long-range transport. The maximum around St. Charles in 79/80 might be attributed to farming activities in the area. Note that, as with acidity and sulfates, NO_3 concentrations were somewhat higher in the smelter shutdown (78/79) than the operating (79/80) year.

- NH_4 (Figures 12a and 12b): the broad features of the NH_4 concentration field were similar to those for NO_3 with a fairly pronounced S-N gradient probably due to long-range transport. The maximum around the Lively station in the 79/80 data is attributed to NH_3 emissions from INCO's Iron Ore Recovery Plant, while that at St. Charles may be due to farming in the area and the proximity of an indoor skating rink, which could be the source of NH_3 emissions (though this does not explain the 78/79 results at St. Charles, since the rink was also in operation then). However, in contrast with SO_4 and NO_3, NH_4 average concentrations in 79/80 were somewhat greater than those in 78/79.

- F (Figures 13a and 13b): for both years, there is no distinct S-N gradients. Maxima are observed for 78/79 and 79/80 at River Valley and Bear Island respectively. The shift may be artificial because in the first year, there were not enough data to estimate an annual concentration at Bear Island. The high F concentrations at Bear Island could result from the presence of the Sherman Mines iron pelletizing plant near this location. Concentrations in 78/89 were in general higher at all stations than those in 79/80.

- Ni (Figures 14a and 14b): maximum values appeared around the Sudbury area; at Hanmer in 78/79 (note Lively station had no data for comparison) and at Lively (secondary maximum at Hanmer) in 79/80. The relative values for the two years were significantly different reflecting the presence of full smelter operations in 79/80. Also it is noted that the gradient near the source is extremely steep reflecting the fact that Ni is in the large particle size range and its scavenging by precipitation is very efficient. The S-N and SW-NE gradients are consistent with the upper precipitation windrose. Ni concentrations in the INCO operating year were in general higher throughout the Sudbury Basin than those during the strike year.

- Cu (Figures 15a and 15b): the Cu concentration patterns for the two study years were very similar to those of Ni with the presence of smelter operations being clearly evident. It is noted that the influence of Cu on precipitation was quite localized as evidenced by the very high concentration of Cu at Lively (in 79/80) and the

gradient to N and NE. The 78/79 data were biased because of the missing values at Lively and Hanmer. Except for stations close to the source, in both years the concentrations at most other stations were comparable.

- Fe (Figures 16a and 16b): the data for Fe are rather difficult to interpret, probably because of the significant contribution from windblown soil. There was a weak maximum in the Sudbury area in 79/80 - not nearly as pronounced as those for Cu and Ni - which may be due to smelting activities.

- Al, Ca, Mg and K (Figures 17 a/b, 18 a/b, 19 a/b and 20 a/b): all of these substances are primarily of soil origin, and their long-term concentration fields do not show any evidence of a smelter contribution.

- Pb, Zn, Cr and Cd (Figures 21 a/b, 22 a/b, 23 a/b, and 24 a/b) The long-term concentration fields for these metals are similar. It is difficult to detect any smelter-related influence for this group, with the exception of Pb, and Cd which show moderately elevated levels around INCO in the 79/80 data (Figures 21b and 24b). This result is somewhat surprising, since an analysis of the event network for the same group of metals showed a fairly significant smelter contribution to the Sudbury area, and a rather efficient wet deposition process (4). Presumably the smelter contribution is largely masked by the "noise" in the cumulative, long-term data. Certainly the smelter contribution of these metals was not as pronounced as that for Cu and Ni (4).

- Na and Cl (Figures 25 a/b, and 26 a/b): the general features for the Na and Cl concentration fields are similar, since these substances have largely a suspected common origin in road salt. There is a broad maximum in the Sudbury area, due to the higher density of vehicle traffic there, with relatively high values also occuring at a few other locations, such as Elliott Lake, where the sampler was located closer to the road than would have been desired.

4.3.2 Deposition Data

Because of precipitation non-uniformity in the greater Sudbury area, one would expect the deposition contours to be modified from their corresponding concentration contours. Figures 27 to 45 are contours of average monthly deposition calculated on an annual basis. The results are presented according to similar categories as those for the concentration profiles.

- H_f (Figures 27a and 27b): comparing the (predominantly) smelter shutdown and operating periods (78/79 and 79/80 respectively), it is difficult to detect any influence from a local smelter source on the long-term H_f deposition in the Sudbury area, which is in agreement with results inferred from the event wet deposition network (4,8). The importance of long-range transport is suggested by the gradual decrease in H_f deposition in the northerly direction, and the higher values in 78/79 as compared to 79/80. The minimum value at St. Charles in 79/80 may be due to neutralization of acidity by local ammonia sources from a nearby indoor skating rink and farming activities.

- H_t (Figures 28a and 28b); the general features of the H_t deposition maps are similar to those for H_f, and the same comments apply in both cases.

- SO_4 (Figures 29a and 29b): during both study periods, there was a gradual decrease of sulfate deposition from south to north, with somewhat higher values for the smelter shutdown year, indicating that long-range transport was the dominant contributor. However, in the 79/80 period, there is a suggestion of a smelter contribution superimposed onto the general background deposition pattern.

- NO_3 (Figures 30a and 30b): the decrease in nitrate deposition from south to north, with no evident smelter effects, shows the importance of long-range transport for this parameter. Although the absence of smelter effects is not surprising (since, as was already pointed out, NO_x emissions from the smelters are small), the fact that the effect due to NO_x emissions in Sudbury also do not appear on the nitrate deposition maps is somewhat unexpected. A nitrate gradient (speculated to be due to urban emissions), was detected in the event network data (4).

- NH_4 (Figures 31a and 31b): the general features of the NH_4 deposition field are similar to those for NO_3. The maximum noted around Sudbury in the 79/80 data is probably due to NH_3 emissions from INCO's Iron Ore Recovery Plant: the minimum around Burwash is not readily explainable. It is interesting to note the pronounced north-south gradient for NH_3, which seems to be more than a

factor-of-two over the study area, and is similar to the corresponding values for SO_4 and NO_3.

- F (Figures 32a and 32b): the fluoride deposition map is difficult to interpret. Values are considerably higher in 78/79 than 79/80. This may be explained partially as an artifact because the laboratory detection limit had improved over the 2 study years. Most of the fluoride concentrations were at the detection limit. The maximum around Bear Island in 79/80 may be due to local industrial activities (see Section 4.3.1).

- Ni (Figures 33a and 33b): the influence of smelting activities on nickel deposition is clearly evident from these figures. Although no data are available from the Lively station for 78/79, a comparison of the 78/79 and 79/80 maps does suggest a smelter contribution to the long-term Ni deposition in the Sudbury area that is several-times the background value. Using a monthly background Ni deposition of 85 ug/m^2, an estimate of the smelter contribution within 40 Km of Sudbury was made from the "hump" in the 79/80 data. The contribution of the smelters came to about 40% of the total Ni deposition, in acceptable agreement with the 67% obtained by an independent analysis of the event deposition results for INCO, and a somewhat lower value for Falconbridge (4).

- Cu (Figures 34a and 34b): the Cu deposition data also show the strong influence of smelting activities seen in the Ni values. As with Ni, there is some uncertainty about the location of the peak in 78/79, due to the unavailability of data at Lively. The

79/80 data show a smelter contribution amounting to more than two times the background. Assuming a background deposition of around 140 ug/m^3, it was estimated that within 40 Km of Sudbury, the smelter contributed about 40% of the total Cu deposition. A different analysis, using recent results from the event deposition network (4), gave a smelter contribution of 69% of the total for INCO, with somewhat lower values than this estimated for Falconbridge. Again, this is considered to be in acceptable agreement, in view of the uncertainties in the data and the relatively crude approximations entailed by the lack of detail in the deposition "humps" around Sudbury.

- Fe (Figures 35a and 35b): as with concentrations, the deposition data for iron are difficult to interpret. Values were comparable in 78/79 and 79/80, and were probably dominated by the windblown soil contribution, although there is a suggestion of a local source influence in the 79/80 data.

- Al, Ca, Mg and K (Figures 36 a/b, 37 a/b, 38 a/b, and 39 a/b): the deposition fields of these soil-related elements do not show any evidence of a smelter contribution. They are probably dominated by local factors, such as ground-cover characteristics, vehicular traffic, etc.

- Pb, Zn, Cr and Cd (Figures 40 a/b, 41 a/b, 42 a/b and 43 a/b): Pb is the only trace metal of this group showing any evidence of a smelter contribution (Fiugre 40b). Otherwise, the patterns for Pb and Zn are

similar, with deposition decreasing in a northerly direction. The deposition patterns for Cr and Cd are rather complex, showing unexplained maxima and minima.

Na and Cl (Figures 44 a/b and 45 a/b): as already mentioned, these substances occur in precipitation mainly due to road salt in traffic-generated aerosols. As with concentration, their general deposition features during each monitoring period were similar, and probably largely reflect local vehicular activities.

5. CONCLUSIONS

A monthly precipitation network consisting of about 20 stations was set up in the greater Sudbury area to study the wet deposition pattern. Based on the data collected over roughly two and half years the following conclusions can be drawn.

- The most acidic sample had a pH of 3.5 and the least acidic one 5.4. The geometric mean pH of all samples collected was 4.1.

- The maximum and minimum concentrations (mg l^{-1}) of the acid-base related materials were: SO_4 = 18.0, 0.3; N-NO_3 = 2.95, 0.15; and N-NH_4 = 3.11, 0.1. The corresponding geometric means were: 3.4, 0.60 and 0.34 mg l^{-1}.

- Maximum and minimum concentrations (mg l^{-1}) of some of the trace metals emitted by smelting were: Fe = 1.43, 0.006; Cu = 1.07, 0.001; Ni = 0.079, 0.001; Pb = 0.067, 0.001; and Zn = 0.31, 0.001. The minimum values of Cu, Ni and Pb corresponded to analytical detection limits. Geometric mean values were: Fe = 0.068, Cu = 0.003; Ni = 0.002; Pb = 0.011 and Zn = 0.010.

- H_f (free hydrogen ions) is strongly correlated with H_t (total hydrogen ions). Strong acids accounted for, on average, 70% of the total acid contents. H_f is better correlated with SO_4 than with NO_3. The correlation between NH_4 and SO_4 as well as NH_4 and NO_3 suggested that these species might be chemically associated.

- Monthly average concentration and deposition fields were constructed for the periods June '78 - May '79 (when smelting acitivities in the Sudbury area were at a minimum due to shutdown of the larger, INCO smelter during most of this period), and June '79 - May '80 (when the smelters were fully operational). The greatest impact of smelting activities on the concentration and deposition field was seen to be for copper and nickel, in agreement with analysis of data from the SES event network (4). Of a second group of trace metals (Pb, Zn, Cr and Cd), only Pb showed a detectable smelter impact. Results for the other substances examined (H_f, H_t, $S0_4$, $N0_3$, NH_4, Fe, Al, Mg, Ca, K, Na and Cl) seemed to be largely governed by non-smelting phenomena, such as long-range transport, wind-blown dust, or vehicular traffic. The event network analyses (4) suggested that the smelter contribution of these substances is generally less than 20% of the total in the Sudbury basin, and evidently the inherent "noise" in the long-term data (due to precipitation variability, sampling and analysis errors, and so on) is large enough to mask any increment due to smelting acitivities.

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TABLE 1: STATION NAMES AND COORDINATES

Station No.	Station	Elevation (m)	Latitude (deg/min/sec/N)	Longitude (deg/min/sec/W)	UTM Easting	Northing	Normal
1	Burwash	230	46 15'46"	80 48'48"	514600	5123000	NB 1422
2	Lake Panache	230	46 16'27"	81 20'42"	473400	5124400	MB 7324
3	Windy Lake	460	46 37'15"	81 27'08"	465600	5163300	MB 6663
4	Hanmer	300	46 39'45"	80 56'37"	504300	5167300	NB 0467
5	Killarney	180	45 59'25"	81 29'18"	462300	5092800	MA 6293
6	St. Charles	230	46 21'43"	80 24'22"	545500	5134300	NB 4534
7	Gowganda	345	47 39'02"	80 46'42"	516800	5277500	NC 1777

TABLE 1: STATION NAMES AND COORDINATES (CONT'D)

Station No.	Station	Elevation (m)	Latitude (deg/min/sec/N)	Longitude (deg/min/sec/W)	UTM Easting	UTM Northing	UTM Normal
8	Elliot Lake	275	46 24'15"	82 39'53"	372600	519800	LB 7239
9	North Bay	290	46 20'05"	79 29'28"	615000	5113300	PB 0203
10	Parry Sound	230	45 20'07"	80 01'33"	577600	5020300	NA 07521
11	Halfway Lake	430	46 54'25"	81 38'05"	451900	5194500	MB 5294
12	Marten River	290	46 44'03"	79 48'15"	592000	5177000	NB 9275
13	Florence Lake	365	47 13'45"	80 33'10"	533900	5230700	NC 3431
14	Ramsey	425	47 26'33"	82 20'15"	399400	5255100	LC 9955
15	Graveyard Lake	365	47 00'00"	81 08'55"	488300	5205000	MC 8805

TABLE 1: STATION NAMES AND COORDINATES (CONT'D)

Station No.	Station	Elevation (m)	Latitude (deg/min/sec/N)	Longitude (deg/min/sec/W)	UTM Easting	UTM Northing	UTM Normal
16	Chiniguchi Lake	305	46 57'51"	80 39'08"	526400	5201000	NB 2699
17	Massey	215	46 13'12"	82 04'37"	417100	5118800	MB 1719
18	River Valley	235	46 33'30"	80 08'15"	566700	5156300	NB 6756
19	Bear Island	305	46 58'25"	80 04'30"	570300	5202200	NC 7002
20	Noelville	220	46 08'05"	80 26'00"	544000	5109300	NB 4409
21	Lively	275	46 26'45"	81 09'00"	488400	5143400	MB 8843
22	Portage Lake	185	45 54'15"	80 33'17"	534500	5083500	NA 3483

TABLE 2: DISTANCE IN Km OF STATIONS FROM THE INCO LIMITED SMELTER IN SUDBURY

Distance (Km)	Stations
0-10	Lively
10-40	Windy Lake Burwash Lake Panache Hanmer
40-70	St. Charles Noelville Killarney Halfway Lake Graveyard Lake Chiniguchi Lake River Valley
70-100	Massey Florence Lake Portage Lake Bear Island Marten River
100-130	North Bay Elliot Lake Gowganda
130-150	Ramsey Parry Sound

TABLE 3: DETAILS OF PRECIPITATION SAMPLE ANALYSES

Parameter	Analysis Method	Detection Limit (mg l^{-1})
pH (for H_f determination)	Radiometer	0.1 pH unit
Total Acidity (for H_t determination)	NaOH titration to pH 8.3 results presented as mg $CaCO_3$ l^{-1}	0.08
SO_4	Ion Chromatography	0.04*
$N\text{-}NO_3$	Ion Chromatography	0.01*
Cl	Ion Chromatography	0.04*
F	Ion Chromatography	0.04*
$N\text{-}NH_4$	Automated phenate-hypochlorite method	0.008
Ca	Flame atomic absorpiton	0.02*
Na	Flame atomic absorpiton	0.02*
K	Flame atomic absorption	0.02*
Mg	Flame atomic absorption	0.02*
Zn	Flame atomic absorption	0.001
Fe	Flameless atomic absorption	0.001
Ni	Flameless atomic absorption	0.001
Cu	Flameless atomic absorption	0.001
Pb	Flameless atomic absorption	0.001
Al	Flameless atomic absorption	0.005
Cr	Flameless atomic absorption	0.0005
Cd	Flameless atomic absorption	0.0001

* Values correspond to lowest values reported.

TABLE 4 SUMMARY OF NETWORK PERFORMANCE+

(* - missing sample; p- partial analysis of sample; 1 1 operating period)

STATION	D	J	F	M	A	M	J	J	J	A	A	S	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
1. Burwash	1		*				P				P																						*1
2. Lake Panache	1*		*		*		*														*												1
3. Windy Lake	1				*								P											*									*1
4. Hanmer	1	*	*	*	P		*	*		*						P		P						*						P			1
5. Killarney	1*								*									*								P	*				*	*	1
6. St. Charles	1	*	*															*			*					*		*					*1
7. Gowganda	1			*		*			*			*	*		*				*		*		*	*						P			*1
8. Elliot Lake	1		P														*	*	*				*							*			1
9. North Bay	1		*													*	*	P											*				1
10. Parry Sound	1		P							*																	*	*					1
11. Halfway Lake (A)																						1*	*	*	*	*1							
Month	D	J	F	M	A	M	J	J	J	A	A	S	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
Year	1977								1978													1979									1980		

+ In 1978, semi-monthly sampling was carried out during the months of July, August and September. For this reason, two entries are listed for each of these months (underlined).

TABLE 4 SUMMARY OF NETWORK PERFORMANCE+ CONT'D

(* - missing sample; p- partial analysis of sample; 1 1 operating period)

STATION	D	J	F	M	A	M	J	J	J	A	A	S	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
12. Marten River									1				*	*									*										*1
13. Florence Lake (A)																						1	*	*	*	*1							
14. Ramsey								1		*			*			*										*						*	1
15. Graveyard Lake (A)														1*		1						1		*	*	*	*	1					
16. Chinguchi Lake (A)								1	*	*	*				*1							1	*		*	P	*	1					
17. Massey								1									*													*			1
18. River Valley								1										*												*			1
19. Bear Island														1	1							1					*						1
20. Noelville								1								*										*							1
21. Lively																	1					*											1
22. Portage Lake														1				*		*							P						*1
Year	1977								1978														1979								1980		

+ In 1978, semi-monthly sampling was carried out during the months of July, August and September. For this reason, two entries are listed for each of these months (underlined).

Table 5: Atypical Smelter Operating Conditions* (from 1978 - 1980)

Time	Industry	Operating Conditions Shutdown	Strike
1978			
July 1 - Aug. 21	Falconbridge	X	
July 17 - Aug. 27	INCO	X	
Sept. 16 - Dec. 31	INCO	X	X
1979			
Jan. 1 - Jun. 7	INCO		X
Jul. 8 - Jul. 22	Falconbridge	X	

*The unspecified periods correspond to normal operations.

Table 6: Statistical Summary of Cumulative Network Concentration Data

CUMULATIVE SAMPLING ANALYSIS RESULTS

SUDBURY ENVIROMENTAL STUDY

THE STATISTICAL TABLE-ALL DATA
(CONCENTRATION)

ALL STATIONS
STATISTICAL PERIOD :771201-800531

PAGE : 1

	VOL.	PH	ACIDITY	HF	HT	SO4	N-NO3 (MG/L)	N-NH4	CL	CA	MG	NA
SAMPLE SIZE	463.	441.	421.	441.	421.	437.	434.	434.	429.	431.	432.	432.
MAXIMUM	8120.	5.44	26.90	0.34	0.54	18.00	2.95	3.110	4.45	3.35	0.51	4.07
MINIMUM	50.	3.47	1.09	0.004	0.02	0.30	0.15	0.008	0.005	0.005	0.005	0.005
RANGE	8070.	1.97	25.81	0.34	0.52	17.70	2.80	3.102	4.44	3.35	0.50	4.06
ARITH. MEAN	1725.		5.99	0.09	0.12	4.01	0.66	0.428	0.30	0.36	0.06	0.23
ARITH. STD. DEV	1071.		2.49	0.05	0.05	2.26	0.32	0.299	0.40	0.39	0.06	0.39
GEOM. MEAN	1338.	4.11	5.60	0.08	0.11	3.49	0.60	0.344	0.21	0.25	0.04	0.12
GEOM. STD. DEV.	0.83	0.05	0.36	0.49	0.36	0.54	0.46	0.715	0.80	0.87	0.89	1.03
1ST QUARTILE	870.	4.00	4.66	0.06	0.09	2.60	0.47	0.253	0.13	0.15	0.03	0.07
2ND QUARTILE	1585.	4.11	5.63	0.08	0.11	3.59	0.63	0.360	0.19	0.25	0.05	0.10
3RD QUARTILE	2370.	4.22	6.66	0.10	0.13	4.80	0.79	0.525	0.30	0.43	0.08	0.20
VOL. WGT. MEAN		4.12 *	5.73	0.08	0.11	3.78	0.59	0.408	0.22	0.29	0.05	0.14

* : Calculated from the corresponding HF value

Table 6: continued

CUMULATIVE SAMPLING ANALYSIS RESULTS

SUDBURY ENVIROMENTAL STUDY

THE STATISTICAL TABLE-ALL DATA
(CONCENTRATION)

ALL STATIONS
STATISTICAL PERIOD :771201-800531

PAGE : 2

(MG/L)

		K	SI	F	FE	CU	NI	PB	ZN	AL	CR	CD
SAMPLE SIZE	:	432.	190.	386.	408.	433.	433.	431.	426.	371.	431.	430.
MAXIMUM	:	0.95	0.30	0.12	1.430	1.070	0.079	0.067	0.310	0.385	0.0450	0.1000
MINIMUM	:	0.005	0.02	0.002	0.006	0.0005	0.0006	0.0005	0.001	0.002	0.0003	0.0001
RANGE	:	0.94	0.27	0.12	1.424	1.069	0.078	0.066	0.309	0.383	0.0448	0.1000
ARITH. MEAN	:	0.10	0.06	0.02	0.098	0.009	0.004	0.014	0.016	0.047	0.0011	0.0021
ARITH. STD. DEV	:	0.10	0.06	0.02	0.136	0.053	0.008	0.008	0.023	0.042	0.0033	0.0060
GEOM. MEAN	:	0.07	0.05	0.02	0.068	0.003	0.002	0.011	0.010	0.036	0.0005	0.0007
GEOM. STD. DEV.	:	0.95	0.70	0.74	0.761	1.128	1.132	0.785	0.865	0.734	1.0187	1.4704
1ST QUARTILE	:	0.04	0.02	0.01	0.041	0.002	0.000	0.009	0.006	0.023	0.0003	0.0003
2ND QUARTILE	:	0.07	0.05	0.02	0.064	0.003	0.002	0.012	0.011	0.035	0.0003	0.0007
3RD QUARTILE	:	0.12	0.05	0.03	0.107	0.008	0.003	0.017	0.016	0.056	0.0010	0.0019
VOL. WGT. MEAN	:	0.08	0.07	0.02	0.067	0.005	0.003	0.012	0.012	0.037	0.0006	0.0013

TABLE 7: SUMMARY OF ACID-RELATED PARAMETER CONCENTRATIONS

Conc. (mg l^{-1})

Station	N	pH Max.	pH Min.	pH G.M.	SO_4 Max.	SO_4 Min.	SO_4 G.M.	$N\text{-}NO_3$ Max.	$N\text{-}NO_3$ Min.	$N\text{-}NO_3$ G.M.
1. Burwash	31	4.31	3.49	4.00	14.0	1.48	4.00	1.47	0.23	0.70
2. L. Panache	27	4.37	3.54	4.06	15.0	0.90	3.70	1.57	0.20	0.62
3. Windy Lake	30	4.69	3.72	4.14	9.90	0.70	2.69	1.40	0..23	0.54
4. Hanmer	26	4.51	3.89	4.12	8.00	2.00	3.87	1.20	0.20	0.52
5. Killarney	26	4.60	3.55	4.05	18.0	1.20	4.59	1.90	0.27	0.81
6. St. Charles	26	4.42	3.75	4.10	8.60	0.80	3.49	2.80	0.30	0.67
7. Gowganda	22	4.82	3.49	4.23	12.0	0.60	2.55	1.53	0.15	0.41
8. Elliott L.	28	4.37	3.75	4.10	9.40	1.75	3.68	1.20	0.32	0.67
9. North Bay	29	5.44	3.77	4.12	8.40	1.85	3.81	1.11	0.26	0.60
10. Parry Sound	29	4.54	3.47	4.06	9.80	0.90	4.09	2.95	0.33	0.79
11. Marten River	20	4.60	3.98	4.21	5.60	0.90	2.53	0.94	0.20	0.46
13. Florence L.	1	4.09	-	-	4.20	-	-	0.37	-	-
14. Ramsey	21	4.83	3.91	4.23	6.80	0.30	2.49	0.84	0.16	0.39
15. Graveyard L	3	4.65	4.14	-	3.50	1.35	-	0.79	0.21	-
16. Chiniguchi L	5	4.11	3.67	3.97	16.0	3.30	5.36	1.08	0.41	0.60
17. Massey	24	4.50	3.89	4.10	8.50	1.30	3.91	1.10	0.36	0.65
18. River Valley	23	4.47	3.52	4.12	10.0	1.00	3.04	1.74	0.22	0.51
19. Bear Island	12	4.66	3.94	4.20	6.30	1.80	3.19	0.84	0.19	0.52
20. Noelville	26	4.75	3.50	4.10	12.2	0.80	3.60	1.16	0.31	0.60
21. Lively	16	4.36	3.90	4.09	11.2	1.30	4.76	1.63	0.30	0.71

Table 3: Statistical Summary of Cumulative Precipitation Concentration Data from June, 1978 to May, 1979

CUMULATIVE SAMPLING ANALYSIS RESULTS

SUDBURY ENVIROMENTAL STUDY

THE STATISTICAL TABLE-ALL DATA
(CONCENTRATION)

ALL STATIONS
STATISTICAL PERIOD :780601-790531

PAGE : 1

			(MG/L)									
	VOL.	PH	ACIDITY	HF	HT	SO4	N-NO3	N-NH4	CL	CA	MG	NA
SAMPLE SIZE :	202.	202.	197.	202.	197.	200.	200.	200.	196.	195.	195.	196.
MAXIMUM :	8120.	4.75	22.50	0.339	0.450	16.00	1.74	3.110	3.80	2.96	0.25	2.70
MINIMUM :	135.	3.47	1.09	0.018	0.022	0.60	0.15	0.008	0.020	0.020	0.005	0.005
RANGE :	7985.	1.28	21.41	0.321	0.428	15.40	1.59	3.102	3.78	2.94	0.24	2.69
ARITH. MEAN :	1765.	++++	6.06	0.096	0.121	4.04	0.62	0.419	0.267	0.332	0.066	0.184
ARITH. STD. DEV :	990.	++++	2.44	0.051	0.049	2.42	0.26	0.344	0.345	0.319	0.051	0.264
GEOM. MEAN :	1480.	4.06	5.62	0.086	0.112	3.43	0.56	0.319	0.19	0.23	0.05	0.12
GEOM. STD. DEV. :	0.65	0.05	0.40	0.460	0.396	0.59	0.47	0.808	0.77	0.93	0.81	0.83
1ST QUARTILE :	1055.	3.98	4.55	0.071	0.091	2.50	0.43	0.244	0.13	0.14	0.03	0.08
2ND QUARTILE :	1705.	4.06	5.70	0.087	0.114	3.65	0.61	0.345	0.19	0.25	0.05	0.11
3RD QUARTILE :	2330.	4.15	6.91	0.105	0.138	4.75	0.78	0.501	0.30	0.40	0.08	0.17
VOL. WGT. MEAN :		4.07*	5.74	0.092	0.115	3.68	0.58	0.398	0.21	0.30	0.06	0.14

***** : INSUFFICIENT DATA
++++ : NOT CALCULATED
* : CALCULATED FROM THE CORRESPONDING HF VALUE

Table 8: continued

CUMULATIVE SAMPLING ANALYSIS RESULTS

SUDBURY ENVIROMENTAL STUDY

THE STATISTICAL TABLE-ALL DATA
(CONCENTRATION)

ALL STATIONS
STATISTICAL PERIOD :780601-790531

		K	SI	F	FE	CU	NI	PB (MG/L)	ZN	AL	CR	CD
SAMPLE SIZE	:	196.	149.	193.	196.	202.	202.	202.	202.	175.	202.	202.
MAXIMUM	:	0.76	0.30	0.12	0.799	1.070	0.029	0.058	0.310	0.277	0.0325	0.0290
MINIMUM	:	0.005	0.025	0.005	0.0130	0.0005	0.0005	0.0005	0.0010	0.0020	0.0003	0.0001
RANGE	:	0.75	0.27	0.11	0.786	1.069	0.028	0.057	0.309	0.275	0.0322	0.0289
ARITH. MEAN	:	0.10	0.07	0.03	0.084	0.010	0.002	0.014	0.017	0.045	0.0008	0.0019
ARITH. STD. DEV	:	0.10	0.06	0.02	0.091	0.075	0.003	0.007	0.027	0.038	0.0024	0.0035
GEOM. MEAN	:	0.07	0.05	0.02	0.062	0.003	0.001	0.013	0.011	0.035	0.0004	0.0007
GEOM. STD. DEV.	:	0.91	0.74	0.73	0.724	1.158	0.885	0.532	0.891	0.713	0.8130	1.5312
1ST QUARTILE	:	0.05	0.02	0.02	0.040	0.001	0.000	0.009	0.006	0.022	0.0003	0.0002
2ND QUARTILE	:	0.07	0.05	0.02	0.053	0.003	0.001	0.014	0.012	0.033	0.0003	0.0008
3RD QUARTILE	:	0.12	0.10	0.04	0.096	0.005	0.002	0.018	0.018	0.055	0.0005	0.0018
VOL. WGT. MEAN	:	0.09	0.07	0.03	0.060	0.004	0.001	0.013	0.013	0.036	0.0005	0.0015

***** : INSUFFICIENT DATA
++++ : NOT CALCULATED

Table 9 : Statistical Summary of Cumulative Precipitation Concentration Data from June, 1979 to May, 1980

CUMULATIVE SAMPLING ANALYSIS RESULTS

SUDBURY ENVIROMENTAL STUDY

THE STATISTICAL TABLE-ALL DATA
(CONCENTRATION)

ALL STATIONS
STATISTICAL PERIOD :790601-800531

					(MG/L)							
	VOL.	PH	ACIDITY	HF	HT	SO4	N-NO3	N-NH4	CL	CA	MG	NA
SAMPLE SIZE :	207.	193.	184.	193.	184.	192.	192.	189.	192.	190.	191.	190.
MAXIMUM :	6075.	4.83	10.69	0.135	0.214	9.30	1.63	1.230	4.45	1.27	0.33	4.07
MINIMUM :	50.	3.87	1.84	0.015	0.037	0.30	0.18	0.030	0.005	0.030	0.005	0.005
RANGE :	6025.	0.96	8.85	0.120	0.177	9.00	1.45	1.200	4.44	1.24	0.32	4.06
ARITH. MEAN :	1983.	++++	5.46	0.069	0.109	3.75	0.64	0.425	0.271	0.279	0.049	0.159
ARITH. STD. DEV :	1074.	++++	1.34	0.022	0.027	1.58	0.25	0.208	0.420	0.206	0.046	0.360
GEOM. MEAN :	1645.	4.19	5.29	0.065	0.106	3.43	0.59	0.378	0.19	0.23	0.03	0.09
GEOM. STD. DEV. :	0.70	0.04	0.26	0.355	0.257	0.44	0.41	0.504	0.74	0.63	0.89	0.94
1ST QUARTILE :	1240.	4.09	4.65	0.054	0.093	2.63	0.48	0.285	0.13	0.15	0.02	0.05
2ND QUARTILE :	1878.	4.17	5.38	0.068	0.107	3.50	0.62	0.370	0.18	0.21	0.03	0.09
3RD QUARTILE :	2575.	4.27	6.14	0.081	0.123	4.52	0.75	0.525	0.25	0.34	0.06	0.13
VOL. WGT. MEAN :		4.18*	5.52	0.070	0.110	3.75	0.58	0.407	0.20	0.26	0.04	0.10

***** : INSUFFICIENT DATA
++++ : NOT CALCULATED
* : CALCULATED FROM THE CORRESPONDING HF VALUE

Table 9 Continued

CUMULATIVE SAMPLING ANALYSIS RESULTS

SUDBURY ENVIROMENTAL STUDY

THE STATISTICAL TABLE-ALL DATA
(CONCENTRATION)

ALL STATIONS
STATISTICAL PERIOD :790601-800531

PAGE : 2

(MG/L)

		K	SI	F	FE	CU	NI	PB	ZN	AL	CR	CD
SAMPLE SIZE	:	190.	0.	192.	186.	188.	188.	188.	188.	185.	188.	188.
MAXIMUM	:	0.95	******	0.09	0.335	0.154	0.079	0.067	0.220	0.235	0.0100	0.0110
MINIMUM	:	0.005	*******	0.002	0.0060	0.0005	0.0005	0.0005	0.0010	0.0060	0.0003	0.0001
RANGE	:	0.94	******	0.09	0.329	0.153	0.078	0.066	0.219	0.229	0.0098	0.0109
ARITH. MEAN	:	0.08	******	0.02	0.080	0.007	0.005	0.011	0.013	0.046	0.0006	0.0009
ARITH. STD. DEV	:	0.09	******	0.01	0.055	0.018	0.010	0.007	0.019	0.036	0.0011	0.0014
GEOM. MEAN	:	0.05	******	0.01	0.065	0.004	0.002	0.009	0.009	0.035	0.0004	0.0005
GEOM. STD. DEV.	:	0.96	******	0.64	0.649	0.988	1.147	0.924	0.762	0.717	0.7798	1.1500
1ST QUARTILE	:	0.03	******	0.01	0.040	0.002	0.001	0.008	0.006	0.022	0.0003	0.0003
2ND QUARTILE	:	0.06	******	0.02	0.066	0.003	0.002	0.011	0.010	0.035	0.0003	0.0005
3RD QUARTILE	:	0.10	******	0.02	0.101	0.006	0.004	0.014	0.014	0.057	0.0005	0.0010
VOL. WGT. MEAN	:	0.07	******	0.02	0.066	0.006	0.004	0.010	0.011	0.038	0.0005	0.0007

***** : INSUFFICIENT DATA
++++ : NOT CALCULATED

Table 10 : Correlation Analysis of Network Concentration Data.

CUMULATIVE SAMPLING ANALYSIS RESULTS -SES

LINEAR CORRELATION COEFFICIENT
99% CONFIDENCE LEVEL
(# OF OBSERVATION PTS)

ALL STATIONS

PERIOD : DEC 3,77-MAY28,80

	VOL	HF	HT	SO4	NO3	NH4	CL	CA	MG	NA	K	SI	F	FE	CU	NI	PB	ZN	AL	CR	CD
VOL	1.000																				
	463																				
HF	-0.14	1.000																			
	437	441																			
HT	-0.18	0.754	1.000																		
	419	420	421																		
SO4	-0.16	0.628	0.752	1.000																	
	434	435	420	437																	
NO3	-0.36	0.468	0.631	0.474	1.000																
	431	432	418	434	434																
NH4		0.332	0.509	0.779	0.501	1.000															
		432	420	432	430	434															
CL	-0.35				0.332		1.000														
	426				428		429														
CA	-0.30	0.177	0.308	0.373	0.300	0.251	0.208	1.000													
	429	429	416	430	427	428	424	431													
MG	-0.34	0.220	0.317	0.516	0.354	0.459	0.150	0.744	1.000												
	430	430	417	431	426	429	425	431	432												
NA	-0.40				0.320		0.945	0.340	0.249	1.000											
	430				428		425	430	431	432											
K	-0.27	0.153	0.239	0.438	0.248	0.456	0.276	0.394	0.497	0.340	1.000										
	430	430	418	431	428	430	425	430	431	432	432										
SI								0.227	0.233			1.000									
								189	189			190									
F	-0.22	0.414	0.425	0.245	0.166	0.152		0.169	0.239		0.177		1.000								
	384	384	376	386	385	383		381	382		382		386								
FE	-0.40	0.143	0.340	0.191	0.457	0.150	0.305	0.431	0.303	0.478	0.281		0.219	1.000							
	408	406	396	406	404	407	398	401	402	403	403		375	408							
CU	-0.13		0.169				0.525			0.437				0.233	1.000						
	430		419				422			427				408	433						
NI	-0.20						0.183	0.181		0.281				0.306	0.248	1.000					
	430						422	425		427				408	433	433					
PB	-0.30	0.397	0.532	0.453	0.435	0.385	0.164	0.354	0.396	0.246	0.238		0.294	0.344		0.286	1.000				
	428	428	417	428	426	429	420	423	424	425	425		382	408		431	431				
ZN	-0.24	0.149	0.217	0.270	0.259	0.221	0.210	0.279	0.327	0.270	0.456			0.245			0.297	1.000			
	423	423	416	423	423	424	419	418	419	420	420			402			424	426			
AL	-0.43		0.228	0.319	0.260	0.225	0.315	0.526	0.442	0.397	0.285		0.154	0.711	0.312	0.209	0.268	0.164	1.000		
	371		360	369	358	370	363	364	365	366	366		355	370	371	371	371	365	371		
CR	-0.29				0.143		0.275	0.395	0.255	0.512	0.274			0.628	0.149	0.289	0.273	0.192	0.498	1.000	
	428				426		420	423	424	425	425			408	431	431	431	424	371	431	
CD	-0.25				0.236		0.330	0.293	0.397	0.401	0.183		0.293	0.159		0.221	0.252	0.223	0.167	0.337	1.000
	427				425		419	422	423	424	424		382	407		430	430	423	370	430	430

Table 11: Regression Analysis of Network Concentration Data.

CUMULATIVE SAMPLING ANALYSIS RESULTS -SES

TWO VARIABLES OF THE LINEAR REGRESSION
(A & B)

ALL STATIONS PERIOD : DEC 3,77-MAY28,80

	VOL	HF	HT	SO4	NO3	NH4	CL	CA	MG	NA	K	SI	F	FE	CU	NI	PB	ZN	AL	CR	CD
VOL	0.0 / 1.000																				
HF		0.0 / 1.000																			
HT		0.050 / 0.821	0.0 / 1.000																		
SO4		1.384 / 30.75	-.052 / 33.89	0.0 / 1.000																	
NO3		0.386 / 3.221	0.183 / 3.877	0.394 / 0.067	0.0 / 1.000																
NH4		0.244 / 2.157	0.066 / 3.062	0.009 / 0.105	0.116 / 0.478	0.0 / 1.000															
CL					0.022 / 0.417		0.0 / 1.000														
CA		0.234 / 1.411	0.129 / 1.672	0.113 / 0.060	0.129 / 0.332	0.221 / 0.326	0.289 / 0.169	0.0 / 1.000													
MG		0.040 / 0.278	0.022 / 0.326	0.010 / 0.013	0.021 / 0.062	0.025 / 0.090	0.055 / 0.019	0.024 / 0.112	0.0 / 1.000												
NA					-.021 / 0.363		-.032 / 0.829	0.109 / 0.345	0.126 / 1.669	0.0 / 1.000											
K		0.069 / 0.341	0.037 / 0.479	0.017 / 0.020	0.044 / 0.078	0.031 / 0.151	0.074 / 0.067	0.060 / 0.105	0.042 / 0.873	0.077 / 0.089	0.0 / 1.000										
SI								0.051 / 0.032	0.045 / 0.254			0.0 / 1.000									
F		0.009 / 0.176	0.002 / 0.187	0.015 / 0.002	0.016 / 0.011	0.020 / 0.009		0.020 / 0.011	0.018 / 0.086		0.020 / 0.033		0.0 / 1.000								
FE		0.061 / 0.451	-.002 / 0.783	0.050 / 0.012	-.037 / 0.205	0.068 / 0.071	0.063 / 0.102	0.036 / 0.180	0.052 / 0.745	0.056 / 0.204	0.060 / 0.392		0.060 / 0.931	0.0 / 1.000							
CU			0.001 / 0.048				-.014 / 0.083			-.006 / 0.070					0.0 / 1.000						
NI							0.002 / 0.004	0.002 / 0.004		0.002 / 0.007				0.002 / 0.017	0.003 / 0.036	0.0 / 1.000					
PB		0.008 / 0.071	0.003 / 0.085	0.007 / 0.002	0.006 / 0.011	0.009 / 0.010	0.012 / 0.004	0.011 / 0.008	0.010 / 0.056	0.012 / 0.006	0.012 / 0.019		0.010 / 0.121	0.011 / 0.020		0.013 / 0.293	0.0 / 1.000				
ZN		0.009 / 0.075	0.003 / 0.102	0.004 / 0.003	0.003 / 0.020	0.008 / 0.017	0.011 / 0.014	0.008 / 0.022	0.007 / 0.149	0.011 / 0.023	0.005 / 0.110			0.011 / 0.052			0.004 / 0.881	0.0 / 1.000			
AL			0.020 / 0.222	0.019 / 0.007	0.019 / 0.044	0.033 / 0.035	0.035 / 0.041	0.025 / 0.065	0.026 / 0.351	0.037 / 0.056	0.035 / 0.126		0.038 / 0.324	0.022 / 0.288	0.041 / 0.855	0.043 / 1.075	0.027 / 1.521	0.041 / 0.273	0.0 / 1.000		
CR															0.001 / 0.009	0.001 / 0.120		0.001 / 0.018	-.001 / 0.033	0.0 / 1.000	
CD					-.001 / 0.004		0.001 / 0.003		-.001 / 0.042	0.001 / 0.007	0.001 / 0.011			0.001 / 0.007		0.001 / 0.170		0.001 / 0.031	0.001 / 0.024	0.001 / 0.619	0.0 / 1.000

Table 12: Annual Monthly Average Concentration Data

PERIODIC CONCENTRATION AVERAGE FOR JUN78 - MAY79

(MICROGRAM/L)

STATION NAME	HT	SO4	N-NO3	N-NH4	BR	CL	CA
BURWASH	114.9185	4370.8828	652.8547	358.3203	****	408.4360	234.0845
LAKE PANACHE	116.2724	3513.3232	578.8269	359.0413	****	169.4336	281.2268
WINDY LAKE	105.0322	3137.2632	575.7788	353.0701	****	208.9980	243.4670
HANMER	106.1891	3453.6255	480.2969	313.8943	****	535.2507	209.9207
KILLARNEY	133.9531	4329.4805	777.2043	467.2166	****	226.1136	359.2959
ST. CHARLES	107.0081	3145.3594	534.8042	309.6653	****	127.8521	275.7637
GOWGANDA	96.0429	3122.9011	447.3301	260.2563	****	111.1320	116.9493
ELLIOTT LAKE	116.7557	3974.7717	621.9949	549.2478	****	416.0005	334.2166
NORTH BAY	123.4767	3982.3271	565.3044	413.8357	****	170.9085	243.5031
PARRY SOUND	116.1021	4203.3203	679.0366	524.5051	****	239.4705	351.5334
MARTEN RIVER	100.5836	2727.4656	476.6670	248.9716	****	312.7012	205.2057
RAMSEY	98.8585	3230.8958	467.3564	265.5413	****	171.5518	353.5842
GRAVEYARD LAKE	101.1999	2949.9988	789.9998	519.9995	****	230.0000	399.9995
CHINIGUCHI LAKE	126.1880	5069.2266	557.6311	444.3054	****	138.5425	854.2708
MASSEY	127.2720	3996.0862	674.7544	435.1704	****	247.4202	330.4539
RIVER VALLEY	114.5801	3313.1121	546.6326	361.5127	****	215.5920	324.5225
BEAR ISLAND	106.0000	3599.9998	719.9998	363.9998	****	240.0000	519.9995
NOELVILLE	117.2183	3704.5503	621.9448	452.6643	****	257.0210	277.6440
LIVELY	121.8190	4302.8672	698.4790	488.1494	****	409.3022	264.6252
PORTAGE LAKE	95.8087	2862.1597	673.9363	345.7004	****	164.9709	199.6752

(MICROGRAM/L)

STATION NAME	MG	NA	K	SI	F	FE	CU
BURWASH	65.9324	264.0059	82.6560	45.2544	36.0418	60.6008	4.3545
LAKE PANACHE	51.5687	133.1603	77.1874	45.2950	24.2856	61.7053	3.8388
WINDY LAKE	52.5722	162.1270	87.7028	43.8204	22.2182	63.8264	2.8495
HANMER	37.4046	380.7598	83.7214	74.8466	21.3840	111.4377	3.8690
KILLARNEY	58.8172	145.6328	75.1918	47.0514	25.5339	59.6705	2.9530
ST. CHARLES	57.8081	104.7563	103.8062	72.6366	25.5570	53.8259	3.3167
GOWGANDA	42.7112	115.7748	62.4855	91.1177	26.5130	52.2085	2.7533
ELLIOTT LAKE	70.1848	284.0466	111.5381	95.5540	25.7524	57.6066	3.0949
NORTH BAY	46.2627	121.7042	67.8948	80.0638	23.9899	47.4125	3.2011
PARRY SOUND	73.3886	107.3657	132.3675	54.6317	24.4470	59.4439	1.8651
MARTEN RIVER	42.1003	219.1057	77.2920	31.3749	22.8808	49.0136	2.5889
RAMSEY	69.7725	111.3851	128.3536	108.9872	30.6533	119.6223	3.9117
GRAVEYARD LAKE	80.0000	149.9999	70.0000	149.9999	70.0000	66.0000	3.0000
CHINIGUCHI LAKE	78.9474	122.6923	105.7895	76.7206	14.0182	74.0810	8.5425
MASSEY	69.8410	153.0705	107.4292	88.6966	26.8177	62.8942	4.2745
RIVER VALLEY	67.6568	95.7680	91.1966	71.1027	44.4901	76.1635	4.1065
BEAR ISLAND	60.0000	140.0000	70.0000	50.0000	30.0000	111.0000	9.0000
NOELVILLE	59.7749	165.3725	117.2887	68.9410	36.3627	88.1826	4.8478
LIVELY	52.7711	443.7429	78.0224	25.0000	20.0000	162.0865	9.4440
PORTAGE LAKE	57.4756	172.2267	76.4679	25.0000	21.5759	66.0075	3.5807

Table 12 Continued

STATION NAME	NI	PB	ZN	AL	CR	CD	HF
	(MICROGRAM/L)						
BURWASH	1.6727	13.5608	10.9871	45.7406	0.6398	2.5936	105.2910
LAKE PANACHE	1.3247	12.9513	10.2437	35.9100	0.4499	1.2353	96.5272
WINDY LAKE	1.5732	11.6659	10.7965	42.4428	0.6726	1.3746	82.1245
HANMER	3.1876	12.2566	11.1251	44.7911	1.1290	4.0301	80.1515
KILLARNEY	0.8878	17.9360	16.1839	37.8042	0.4387	1.3622	94.5342
ST. CHARLES	0.8916	12.4386	15.0305	28.9359	0.2646	1.7830	86.1017
GOWGANDA	1.3237	9.7868	8.5664	18.5171	0.6052	1.3280	83.9234
ELLIOTT LAKE	1.7033	15.2030	12.6617	40.3904	0.7440	1.9711	83.7835
NORTH BAY	1.2349	14.6489	14.5198	34.5295	0.5657	0.7100	98.4005
PARRY SOUND	0.6426	13.8743	9.6723	44.1238	0.3687	2.0198	99.0859
MARTEN RIVER	0.9290	10.0438	7.6997	27.0046	0.4367	0.6831	69.6802
RAMSEY	1.4596	10.7818	13.5062	74.0389	0.3598	0.4131	78.3186
GRAVEYARD LAKE	0.5000	22.0000	28.0000	47.0000	0.5000	0.2000	64.5656
CHINIGUCHI LAKE	2.6235	13.4696	21.0668	33.8644	0.3335	0.6872	96.0718
MASSEY	1.1029	17.2873	17.3030	35.4708	0.5211	1.0320	96.0475
RIVER VALLEY	1.2921	14.1172	13.5261	37.7930	0.5579	5.7998	91.5842
BEAR ISLAND	2.0000	23.0000	24.0000	54.0000	0.5000	0.9000	47.8631
NOELVILLE	1.1323	12.6148	16.3058	39.0417	0.5857	0.9350	88.4574
LIVELY	5.3719	16.4098	17.9002	62.0290	1.0795	0.7187	83.4818
PORTAGE LAKE	1.8688	11.0343	11.1360	52.7467	0.2500	1.9716	69.8541

*****: NO DATA

Table 12 Continued

PERIODIC CONCENTRATION AVERAGE FOR JUN79 - MAY80

STATION NAME	(MICROGRAM/L)						
	HT	SO4	N-NO3	N-NH4	BR	CL	CA
BURWASH	119.1617	3827.7979	670.7385	371.9143	****	205.9303	250.2493
LAKE PANACHE	118.0094	4163.3242	689.4932	427.2637	****	185.2454	311.2292
WINDY LAKE	98.9686	2897.6655	508.9314	300.8389	****	205.2715	254.2174
HANMER	117.7735	4157.4570	616.0730	446.7498	****	276.7510	236.6629
KILLARNEY	115.2547	4128.4648	716.4473	499.7031	****	225.4508	345.9497
ST. CHARLES	116.5060	3851.0962	828.7546	528.7998	****	224.3278	297.3372
GOWGANDA	77.8846	2736.4109	382.9536	307.9807	****	183.3113	148.9988
ELLIOTT LAKE	101.7623	3604.4001	662.1306	451.4404	****	401.1506	398.4089
NORTH BAY	110.2214	3697.2231	609.3665	352.7141	****	224.1715	216.1632
PARRY SOUND	117.2425	3925.7190	742.8379	484.6633	****	207.9857	433.3223
MARTEN RIVER	92.4380	2619.3071	476.5815	251.0369	****	190.3870	152.5682
FLORENCE LAKE	109.5999	4199.9922	369.9995	439.9995	****	140.0000	180.0000
RAMSEY	95.4388	3050.4504	370.3044	331.0483	****	161.3447	214.9714
GRAVEYARD LAKE	74.1789	2168.5791	286.1467	305.6877	****	172.8441	191.8807
CHINIGUCHI LAKE	127.9695	4713.9062	463.0459	355.4302	****	145.6953	288.8738
MASSEY	111.1343	4064.2886	666.8032	473.6421	****	257.5625	302.0793
RIVER VALLEY	107.3669	3090.9067	545.6338	344.3430	****	151.5307	176.8062
BEAR ISLAND	110.0685	3599.3931	530.3677	329.1365	****	156.2862	211.0599
NOELVILLE	110.9070	3574.5916	594.6187	391.4578	****	163.6433	192.5670
LIVELY	132.9041	5295.8437	692.1143	717.6846	****	304.0024	226.3154
PORTAGE LAKE	116.3721	3997.4280	708.9817	453.7568	****	182.0218	285.9158

STATION NAME	(MICROGRAM/L)						
	MG	NA	K	SI	F	FE	CU
BURWASH	41.0386	102.5332	51.4683	*****	16.5077	66.2836	4.3439
LAKE PANACHE	48.6450	130.3757	81.0263	*****	15.5201	66.4530	6.9950
WINDY LAKE	42.5914	97.3730	97.1225	*****	16.9304	59.5517	3.8057
HANMER	37.8634	134.1855	86.1079	*****	20.0373	81.2987	14.2327
KILLARNEY	59.5102	114.1818	110.2579	*****	18.3974	109.4516	3.9742
ST. CHARLES	48.6756	97.0329	95.6568	*****	15.2326	78.1300	5.1103
GOWGANDA	28.2178	162.4126	113.1490	*****	13.0997	50.8936	2.2738
ELLIOTT LAKE	69.2328	241.7581	122.4872	*****	16.9356	70.7840	2.2061
NORTH BAY	32.4122	121.9131	48.0891	*****	13.0485	96.8832	4.1518
PARRY SOUND	67.3366	99.7671	56.2512	*****	13.2781	109.4777	2.7582
MARTEN RIVER	38.5938	121.4061	25.0599	*****	9.4205	45.0706	1.7174
FLORENCE LAKE	40.0000	50.0000	40.0000	*****	20.0000	31.0000	1.0000
RAMSEY	30.7405	68.1124	64.0761	*****	16.6393	52.5780	3.0319
GRAVEYARD LAKE	25.2294	87.6147	60.0000	*****	20.0000	70.4863	2.6193
CHINIGUCHI LAKE	54.3046	42.7814	52.7814	*****	23.8741	34.4039	3.4305
MASSEY	44.7559	166.9951	55.9372	*****	14.4489	69.1088	3.1507
RIVER VALLEY	23.2259	65.9259	53.9575	*****	18.4386	42.6807	2.5799
BEAR ISLAND	39.2756	74.3087	126.3335	*****	27.1617	49.7063	2.2520
NOELVILLE	47.3340	69.9405	65.4869	*****	16.1293	41.0311	4.5005
LIVELY	36.5427	176.9915	69.1134	*****	20.0723	132.2162	55.0651
PORTAGE LAKE	51.3909	87.7240	61.4817	*****	16.0016	80.8315	4.0479

Table 12 Continued

STATION NAME	NI	PB	ZN	AL	CR	CD	HF
				(MICROGRAM/L)			
BURWASH	1.8846	11.8940	19.0503	45.1844	0.2621	0.6851	75.9146
LAKE PANACHE	3.9022	10.5410	10.6796	40.6071	0.4644	0.6052	74.0718
WINDY LAKE	3.3246	7.7111	7.9246	34.2520	0.5702	0.7337	53.4834
HANMER	8.3197	11.5508	12.1147	47.6815	0.4383	1.0069	74.1359
KILLARNEY	4.1334	15.6143	15.7604	64.0904	0.5584	0.5908	67.1546
ST. CHARLES	3.5366	10.8837	14.6731	54.9409	0.3589	1.1635	66.5688
GOWGANDA	1.3535	6.2212	8.1718	27.4095	0.4542	1.4360	46.0929
ELLIOTT LAKE	1.2579	11.6157	8.7631	59.9807	0.6483	1.1937	60.6039
NORTH BAY	2.7034	11.7443	10.8925	51.3060	0.9797	0.8649	64.8675
PARRY SOUND	1.4402	12.2408	10.8326	59.2941	0.5365	0.8704	71.6581
MARTEN RIVER	1.1950	7.5289	6.3334	27.2184	0.2710	0.3737	53.2451
FLORENCE LAKE	0.5000	8.0000	18.0000	19.0000	0.2500	0.1000	81.2832
RAMSEY	1.2495	7.2086	6.3203	33.4010	0.3956	0.1855	55.6970
GRAVEYARD LAKE	8.8601	7.1422	50.6284	14.5688	0.2500	0.2239	41.4455
CHINIGUCHI LAKE	1.1457	8.8609	30.6953	12.5563	0.2500	0.1570	100.2414
MASSEY	2.8916	11.0115	12.4058	37.5418	0.4824	0.4003	71.2099
RIVER VALLEY	1.7634	8.8033	9.3115	22.9287	0.5355	1.0583	62.0565
BEAR ISLAND	1.4457	7.7874	6.8764	23.7428	0.3858	0.5989	72.3010
NOELVILLE	2.3301	9.7737	10.3762	33.0794	0.3454	0.3158	73.9661
LIVELY	36.9833	19.8209	13.6482	37.6822	0.4737	1.1878	84.0283
PORTAGE LAKE	1.8418	11.0878	11.1865	48.0770	0.3303	0.9138	78.7780

*****: NO DATA

Table 13: Annual Monthly Average Deposition Data

MONTHLY DEPOSITION AVERAGE OVER A PERIOD OF JUN78 - MAY79

(MICROGRAM/M**2)

STATION NAME	HT	SO4	N-NO3	N-NH4	BR	CL	CA
BURWASH	9583.1875	355872.812	59825.5703	29815.1406	****	30192.2617	19295.9023
LAKE PANACHE	9498.3594	266484.062	50370.0117	28329.8633	****	13660.0156	17341.4297
WINDY LAKE	9134.4219	224907.875	50153.2578	22410.1484	****	17708.8750	15827.1523
HANMER	8512.3750	281124.687	40024.6953	24695.2344	****	27904.8320	16016.6211
KILLARNEY	11670.8984	353368.500	69418.6875	37285.3125	****	19404.5586	27171.6758
ST. CHARLES	9017.9687	245830.687	47285.0000	25628.8750	****	10924.8867	18765.5859
GOWGANDA	6931.3320	200728.062	32628.3164	15077.7930	****	7830.5117	7743.5273
ELLIOTT LAKE	9500.3008	311832.937	50771.1211	41499.0469	****	25527.2539	25448.2305
NORTH BAY	10068.8359	320632.812	46126.9180	32181.7930	****	14379.0469	17334.5859
PARRY SOUND	10552.6211	375685.937	64987.9336	45054.3516	****	22542.0156	25318.3125
MARTEN RIVER	8561.6641	223165.937	40683.1875	17297.9258	****	21147.0820	14031.1641
RAMSEY	7961.5586	238251.625	36294.1055	14892.0469	****	13429.9844	18935.9219
GRAVEYARD LAKE	4400.6797	128280.500	34353.0977	22612.1211	****	10001.5352	17393.9531
CHINIGUCHI LAKE	11075.3164	415263.812	51307.6602	35762.0664	****	12961.2812	77445.5625
MASSEY	10710.7187	332483.625	56662.0234	33984.4570	****	21010.9062	20643.7969
RIVER VALLEY	10479.0508	284772.375	51829.3555	28797.3516	****	17125.9648	19762.9883
BEAR ISLAND	7165.5820	243359.500	48671.8086	24606.3711	****	16223.9727	35151.8984
NOELVILLE	10202.1250	307078.937	56445.0508	36401.4609	****	20610.5508	19795.3008
LIVELY	9003.3867	297814.250	53964.2539	26575.7812	****	25248.1211	16867.8984
PORTAGE LAKE	9577.9336	259660.375	67902.5625	30628.3828	****	16617.0977	12224.9102

(MICROGRAM/M**2)

STATION NAME	MG	NA	K	SI	F	FE	CU
BURWASH	5361.3711	17812.1797	7083.1836	3687.6748	3056.7786	5048.2422	333.7949
LAKE PANACHE	4504.3594	10510.8086	5924.6406	3475.7395	1763.2275	4964.9648	239.2481
WINDY LAKE	3683.0530	13446.7227	5137.6758	3446.1135	1877.8411	5718.3125	194.1715
HANMER	3026.9138	19441.8281	6870.3984	5670.1992	1691.9736	7949.5234	282.4766
KILLARNEY	4218.3086	11703.2578	6538.5898	3959.2981	2081.8997	4973.5195	211.1514
ST. CHARLES	4635.5625	6886.5391	6963.4453	5265.8672	2121.0955	4090.8159	150.5710
GOWGANDA	2361.7644	5795.2617	3750.3118	5049.2617	1889.1448	3708.3164	165.3369
ELLIOTT LAKE	5312.9297	16592.0117	8133.0156	6474.8047	1936.7739	4607.8750	189.4842
NORTH BAY	3445.6699	9911.2187	4223.5273	5190.8633	1779.7329	3984.2063	211.0429
PARRY SOUND	6285.4844	7732.3984	8948.0391	4730.9258	2049.5291	5802.1523	166.0176
MARTEN RIVER	3096.8782	14384.5742	4513.4883	2589.1973	1838.3269	4246.5078	140.8891
RAMSEY	3963.2573	8853.8867	8833.6328	6171.0430	2345.3413	6999.3203	204.6729
GRAVEYARD LAKE	3478.7937	6522.7461	3043.9441	6522.7461	3043.9441	2870.0007	130.4547
CHINIGUCHI LAKE	7087.4453	11023.5156	8708.6172	7290.3594	1284.3372	6054.0781	554.4756
MASSEY	5559.6992	12802.7891	6845.6562	5653.9258	1896.6021	5561.8945	307.2332
RIVER VALLEY	4812.4102	8352.3984	6593.9453	5927.8164	3857.4365	6075.7344	195.6115
BEAR ISLAND	4055.9937	9463.9648	4731.9844	3379.9915	2027.9958	7503.5898	608.3987
NOELVILLE	4374.3750	12167.8945	8536.7070	5089.5156	2829.3022	6903.6250	283.2288
LIVELY	2971.2456	22852.8242	3369.3132	1799.0503	1439.2471	11613.4531	617.3457
PORTAGE LAKE	4484.8672	13704.5742	4798.0586	2500.4104	2078.8342	6065.1523	317.2524

Table 13 Continued

(MICROGRAM/M**2)

STATION NAME	NI	PB	ZN	AL	CR	CD	HF
BURWASH	121.1810	1219.7271	893.2910	3319.8206	43.5360	131.4528	8225.5352
LAKE PANACHE	102.3542	1108.3596	816.6360	2432.6785	34.8830	82.0235	7871.0977
WINDY LAKE	126.2840	938.6812	846.1204	3076.7983	46.9356	42.4543	6940.6992
HANMER	190.4950	999.3313	895.4746	3583.4663	59.6130	152.0669	6176.6406
KILLARNEY	69.4889	1588.2651	1313.7490	3270.5061	35.2252	63.2151	8231.0586
ST. CHARLES	64.6887	1002.2671	810.8499	2385.5647	22.6466	73.0912	7150.6328
GOWGANDA	87.8941	693.8716	552.3987	1348.2942	37.5788	75.8333	5935.7656
ELLIOTT LAKE	111.2799	1226.6526	956.0891	3218.4907	39.1394	115.5868	6173.0078
NORTH BAY	98.2054	1209.4194	1061.2161	2729.6252	43.9026	38.4510	7722.3867
PARRY SOUND	56.1502	1258.2053	892.6411	3919.2998	31.7271	118.6041	6141.6914
MARTEN RIVER	73.8680	867.6191	630.5366	2202.3828	33.9830	42.6168	5843.6289
RAMSEY	102.1814	679.0811	766.2358	4216.2617	29.3831	31.3091	6288.8125
GRAVEYARD LAKE	21.7424	956.6665	1217.5793	2043.7905	21.7424	8.6970	2807.6350
CHINIGUCHI LAKE	172.0325	965.6641	1930.9094	2974.6335	27.9601	47.7209	8431.8047
MASSEY	84.1381	1399.3938	1336.5125	2903.1892	39.8222	61.8078	7968.7969
RIVER VALLEY	91.5628	1341.6843	950.4419	3109.3875	41.9842	159.9041	8351.4570
BEAR ISLAND	135.1998	1554.7952	1622.3950	3650.3855	33.7999	60.8399	3235.5400
NOELVILLE	85.9379	1142.8274	1257.9929	3264.1370	43.0495	48.6458	7750.4648
LIVELY	313.3743	1208.0684	1354.0681	4286.5000	64.1402	37.3054	6124.9805
PORTAGE LAKE	139.9014	1079.7788	1049.4209	4308.0273	25.0042	191.4642	7007.3477

*****: NO DATA

Table 13 Continued

MONTHLY DEPOSITION AVERAGE OVER A PERIOD OF JUN79 - MAY80

(MICROGRAM/M**2)

STATION NAME	HT	SO4	N-NO3	N-NH4	BR	CL	CA
BURWASH	9032.5781	271475.000	51606.2695	23512.1875	****	15532.6680	18305.5156
LAKE PANACHE	8319.3047	284992.687	48478.6328	30183.3086	****	13619.1055	19051.0859
WINDY LAKE	7260.1484	200509.562	40438.2578	23272.7500	****	15191.2969	15073.7695
HANMER	8429.9883	298602.562	44280.1094	31730.1523	****	19497.4961	16898.9766
KILLARNEY	8255.8750	303483.687	50099.3359	36784.6016	****	15414.9648	24100.1055
ST. CHARLES	7419.7148	245520.000	50223.1406	31974.6836	****	14557.1758	17767.4922
GOWGANDA	4345.9023	158584.500	24025.6641	15369.6367	****	8647.4805	8258.6172
ELLIOTT LAKE	6004.4570	210842.437	41041.5469	27042.1367	****	19361.6562	22511.1641
NORTH BAY	7807.0469	252313.312	43232.4219	24686.1445	****	15041.6172	15638.5820
PARRY SOUND	8835.4219	300458.187	56791.6992	36722.3828	****	15567.0547	31648.5547
MARTEN RIVER	8237.5508	219375.937	42986.3242	20313.4570	****	14361.2461	12557.5469
FLORENCE LAKE	10674.9375	409072.250	36037.5312	42855.3789	****	13635.8320	17531.7305
RAMSEY	4469.3242	122912.375	20319.0352	15317.9531	****	8163.0937	9003.7227
GRAVEYARD LAKE	7216.9492	209436.000	27845.9453	29774.7070	****	16827.6992	18695.2930
CHINIGUCHI LAKE	11971.5859	439619.875	43362.4883	32590.8398	****	13577.6328	26977.3047
MASSEY	7307.3867	271895.000	45423.8281	32390.5820	****	13104.0000	19759.2031
RIVER VALLEY	9006.3086	261791.750	45244.2344	28783.7344	****	10319.1562	15013.2695
BEAR ISLAND	8248.0000	251792.937	40299.6992	22878.2930	****	11767.3281	15254.2031
NOELVILLE	8960.7031	280582.062	46998.2617	30874.8437	****	13198.0273	14630.5078
LIVELY	8798.4141	343114.687	46473.6250	46967.6133	****	18765.4961	15516.0234
PORTAGE LAKE	9162.0000	298964.125	56361.6758	34480.9766	****	13745.0195	19870.3906

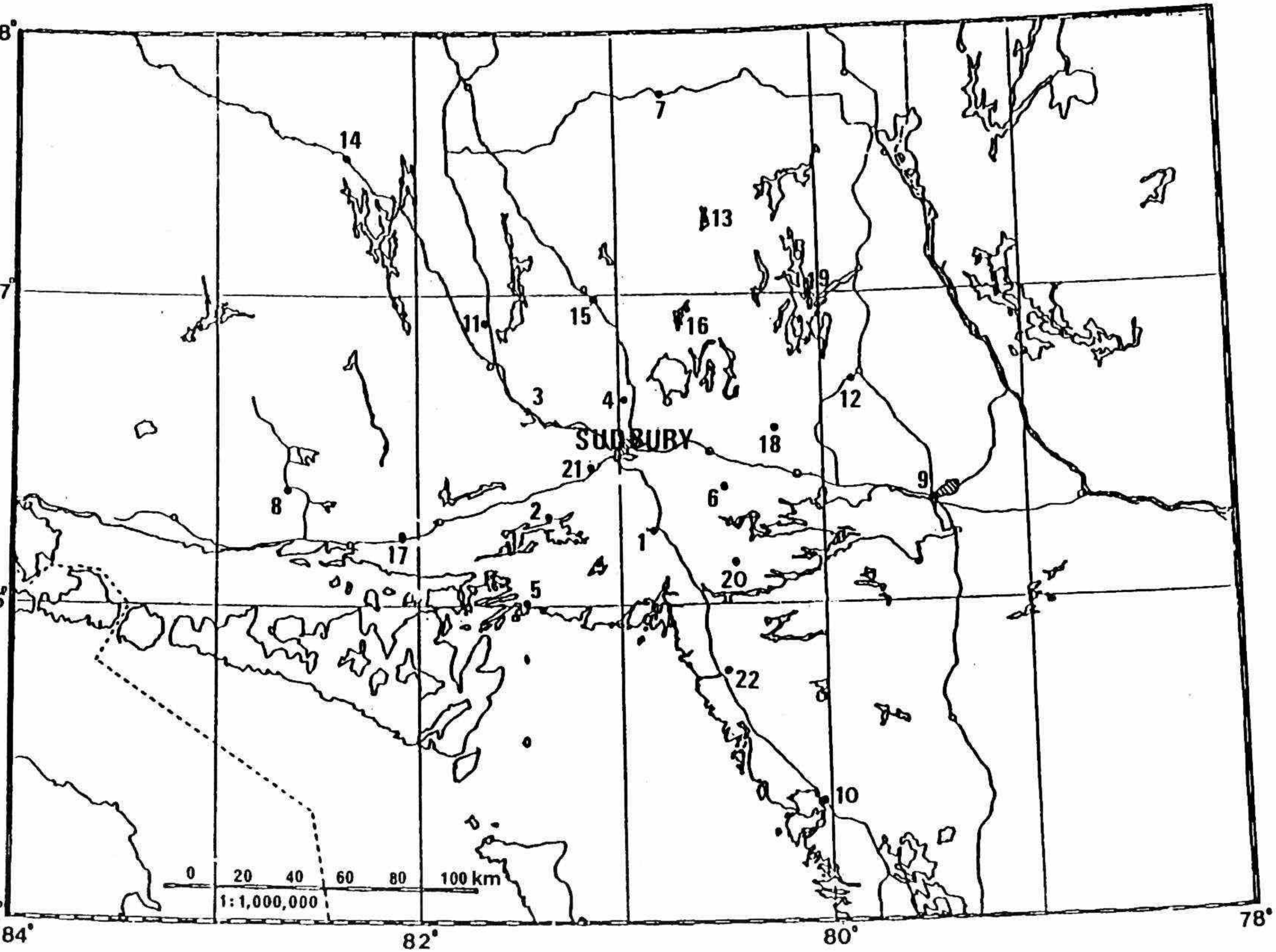
(MICROGRAM/M**2)

STATION NAME	MG	NA	K	SI	F	FE	CU
BURWASH	2857.6750	6489.3711	3684.7920	*****	1202.5439	4570.0078	302.5667
LAKE PANACHE	2605.1433	8232.2500	4662.0234	*****	1107.4963	4847.3672	399.2908
WINDY LAKE	2172.2761	7305.3437	4449.8633	*****	1093.7390	4705.6406	285.8398
HANMER	2562.3755	8118.8320	5192.7422	*****	1367.1008	5910.8828	891.4307
KILLARNEY	4061.2422	7028.7383	7726.1992	*****	1299.2324	7608.8984	280.8584
ST. CHARLES	2766.3616	5873.4648	4929.0937	*****	880.1802	4840.1133	260.9404
GOWGANDA	1178.8843	6045.3945	2779.2263	*****	722.2090	2659.2500	124.6431
ELLIOTT LAKE	3530.7405	9476.1562	3886.1228	*****	1021.5110	4297.0273	126.8279
NORTH BAY	2125.1045	6670.9023	3048.2578	*****	942.8169	6167.7930	263.4565
PARRY SOUND	4684.5703	5828.4570	3759.8267	*****	1044.4915	8106.3242	177.6208
MARTEN RIVER	2474.3833	7173.9531	1728.3735	*****	742.9446	3473.4497	137.6714
FLORENCE LAKE	3895.9602	4869.9336	3895.9602	*****	1947.9885	3019.3601	97.3994
RAMSEY	1192.8899	3391.9973	2815.0000	*****	726.6436	2971.3845	129.8542
GRAVEYARD LAKE	2338.6697	8513.4062	5790.1055	*****	1930.0439	6474.8477	247.1821
CHINIGUCHI LAKE	5084.3672	3722.6990	4700.9297	*****	2235.3679	3163.2515	321.3113
MASSEY	2726.7007	9082.6953	3269.1152	*****	865.4324	4770.2187	200.3219
RIVER VALLEY	1621.9031	4082.7988	3690.5984	*****	905.2993	3669.5305	201.2616
BEAR ISLAND	2367.7881	4868.4687	7990.1953	*****	1466.1453	4127.2461	161.4516
NOELVILLE	2607.4102	5476.7969	3872.3828	*****	931.1675	3246.0298	341.3618
LIVELY	2364.6763	10132.2656	3572.1450	*****	1169.0891	8608.2812	2326.1777
PORTAGE LAKE	3432.5212	5889.6953	3610.1460	*****	1128.4084	6128.5352	280.5540

Table 13 Continued

				(MICROGRAM/M**2)			
STATION NAME	NI	PB	ZN	AL	CR	CD	HF
BURWASH	124.7373	753.5872	873.0156	2716.2310	20.7938	42.5485	5546.9687
LAKE PANACHE	194.2094	650.6055	696.9548	2585.5454	30.3586	37.4232	5136.2305
WINDY LAKE	247.3587	498.3567	554.9919	2584.3401	41.3743	51.6595	3906.2283
HANMER	544.8857	683.7078	675.9719	3379.8657	30.0964	46.3932	5280.3672
KILLARNEY	212.3147	1059.0696	965.9102	4474.0859	36.6132	31.5498	4755.3867
ST. CHARLES	164.3462	570.1768	936.7227	3198.9795	21.4848	54.9688	4141.5273
GOWGANDA	70.9785	335.5559	408.2407	1487.3855	24.6611	69.8537	2655.8008
ELLIOTT LAKE	72.8520	618.9612	525.7168	3487.9558	28.3691	44.5299	3566.4163
NORTH BAY	135.5848	713.3098	707.3579	3390.5840	42.9607	40.0520	4668.5195
PARRY SOUND	80.3494	773.3657	776.4370	4378.0234	36.9804	55.5788	5361.5469
MARTEN RIVER	92.1328	558.5547	513.6191	2348.8870	24.0102	27.5795	4741.3125
FLORENCE LAKE	48.6997	779.1958	1753.1853	1850.5818	24.3498	9.7399	7916.8945
RAMSEY	50.6593	320.8535	320.1069	1786.5300	19.4612	8.2606	2562.1506
GRAVEYARD LAKE	571.4951	695.8125	4520.4453	1414.3523	24.1257	19.8321	3961.4473
CHINIGUCHI LAKE	102.2210	829.8411	2830.5759	1132.2341	23.3400	14.1529	9386.9141
MASSEY	166.0020	591.4065	801.3833	2425.0461	27.6363	18.7312	4558.7734
RIVER VALLEY	132.8388	640.3154	607.0842	1944.3933	36.2693	67.3152	5271.1875
BEAR ISLAND	106.6198	459.1538	486.5872	1849.0505	26.6551	41.5316	5135.0508
NOELVILLE	142.2392	725.4368	820.5205	2445.2969	25.5043	19.7001	5881.1406
LIVELY	1825.0735	1244.1826	914.1128	2372.8901	28.0826	58.6402	5430.4219
PORTAGE LAKE	125.8955	734.2498	820.4683	3043.9905	24.0615	40.7066	6169.3867

*****: NO DATA



STATIONS

1. Burwash
2. Lake Panache
3. Windy Lake
4. Hanmer
5. Killarney
6. St. Charles
7. Cowganda
8. Elliott Lake
9. North Bay
10. Parry Sound
11. Halfway Lake
12. Marten River
13. Florence Lake
14. Ramsey
15. Graveyard Lake
16. Chiniguchi
17. Massey
18. River Valley
19. Bear Island
20. Noelville
21. Lively
22. Portage Lake

Figure 1: SES Cumulative Precipitation Network

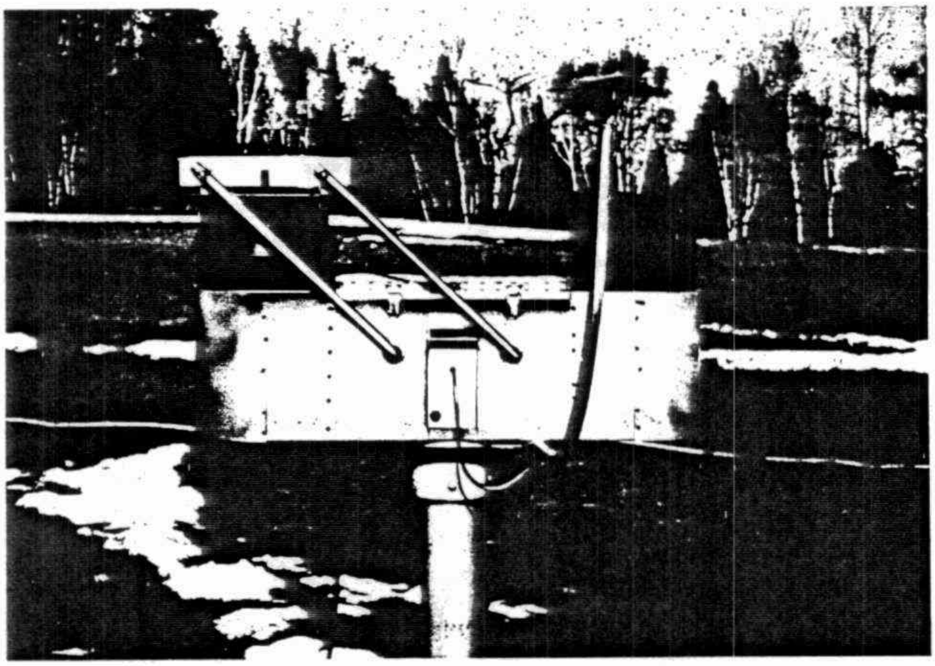


Figure 2: SANGAMO SAMPLER

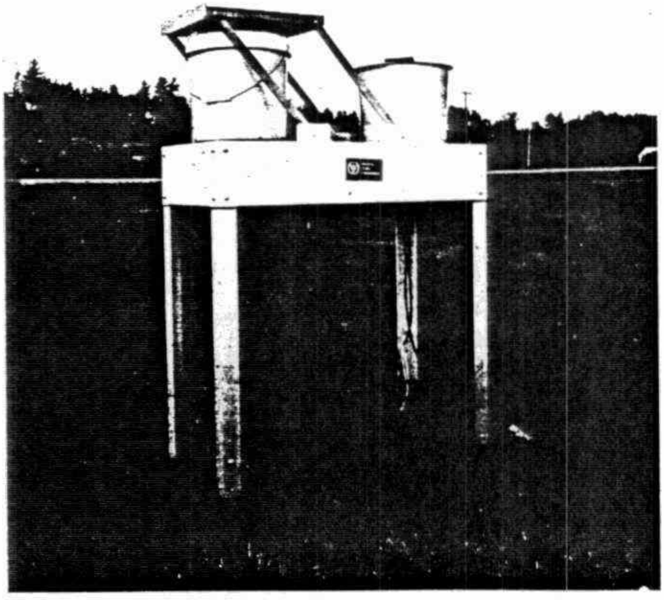


Figure 3: AEROCHEM METRICS SAMPLER

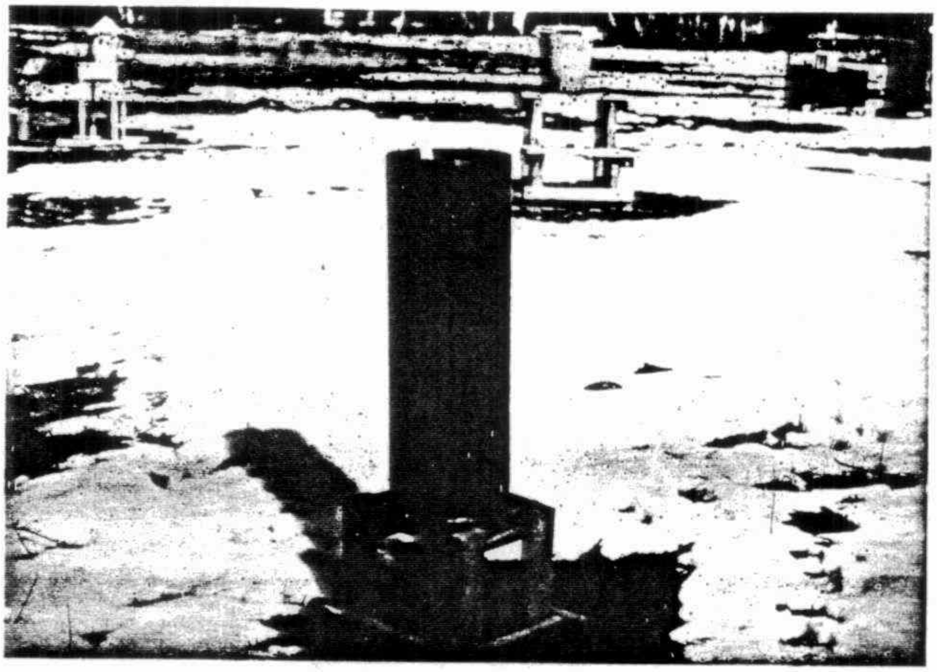


Figure 4: STORAGE GAUGE

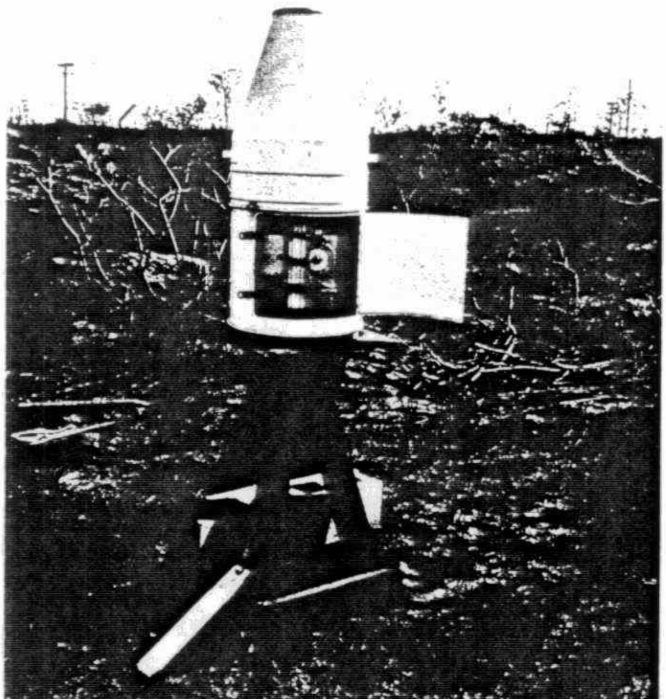


Figure 5: FISHER AND PORTER RECORDING RAIN GAUGE

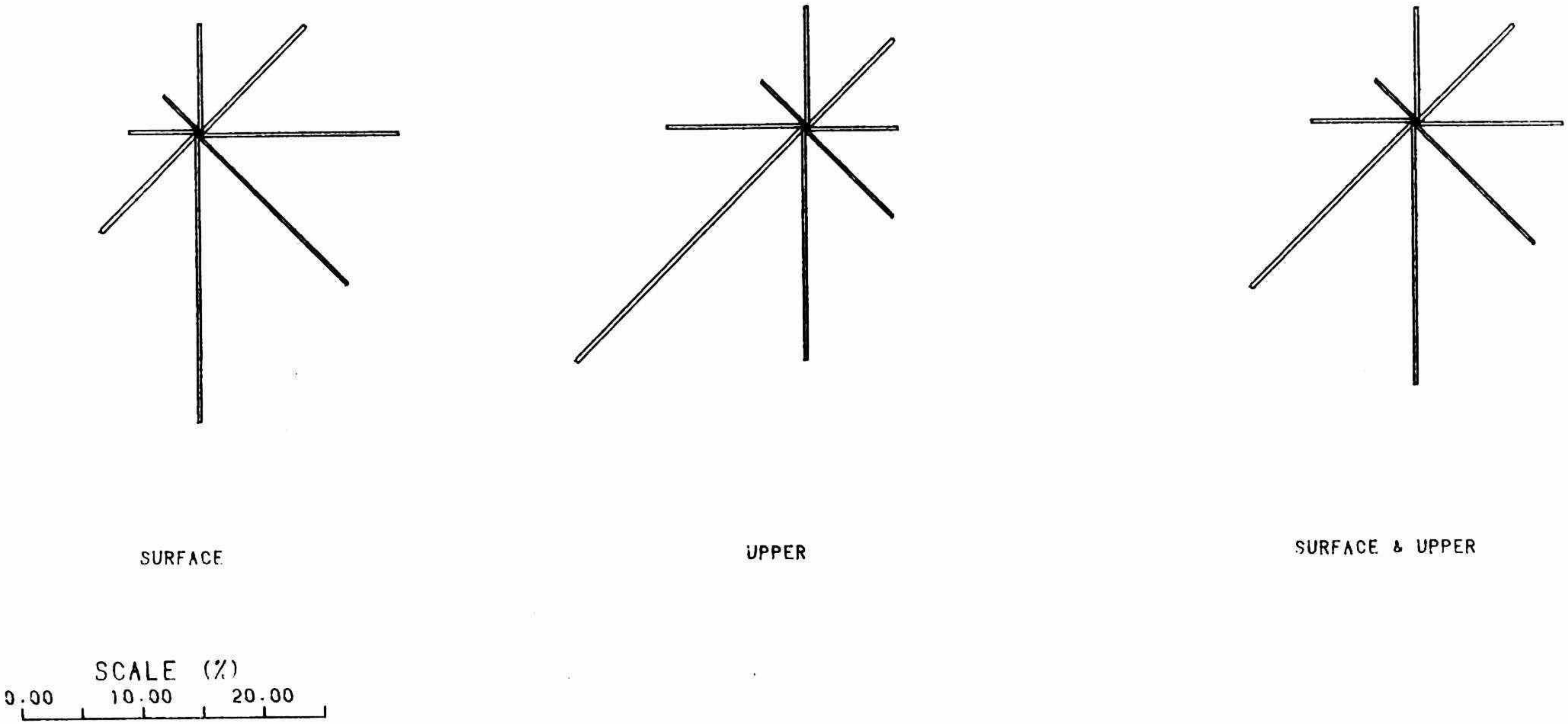


Figure 6
PRECIPITATION WIND ROSES FOR PERIOD FROM JULY 78 TO MAY 79
(SUDBURY)

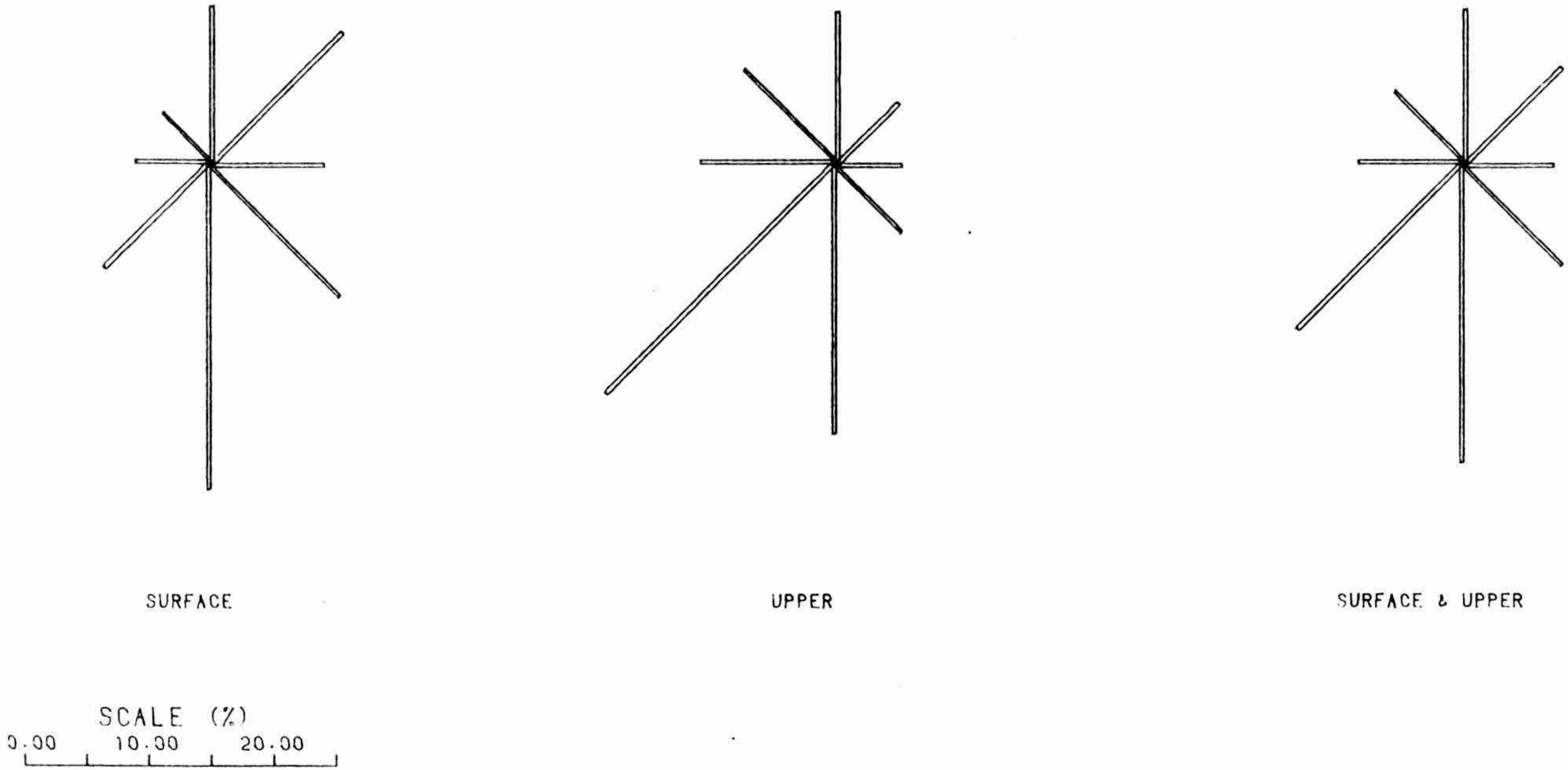


Figure 7

PRECIPITATION WIND ROSES FOR PERIOD FROM JUN 79 TO MAY 80
(SUDBURY)

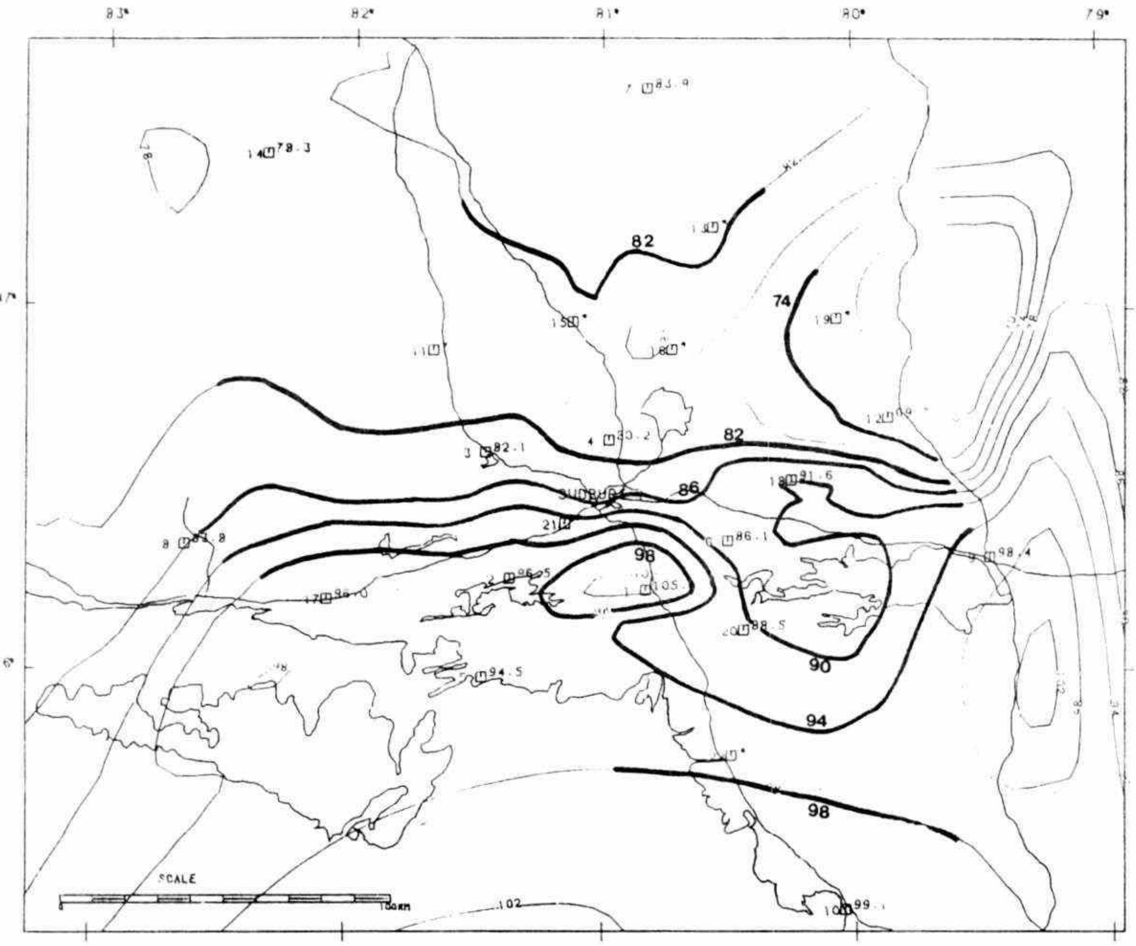


Figure 8A: AVERAGE MONTHLY CONCENTRATION (UG/L) OF H_f - JUN 78 to MAY 79

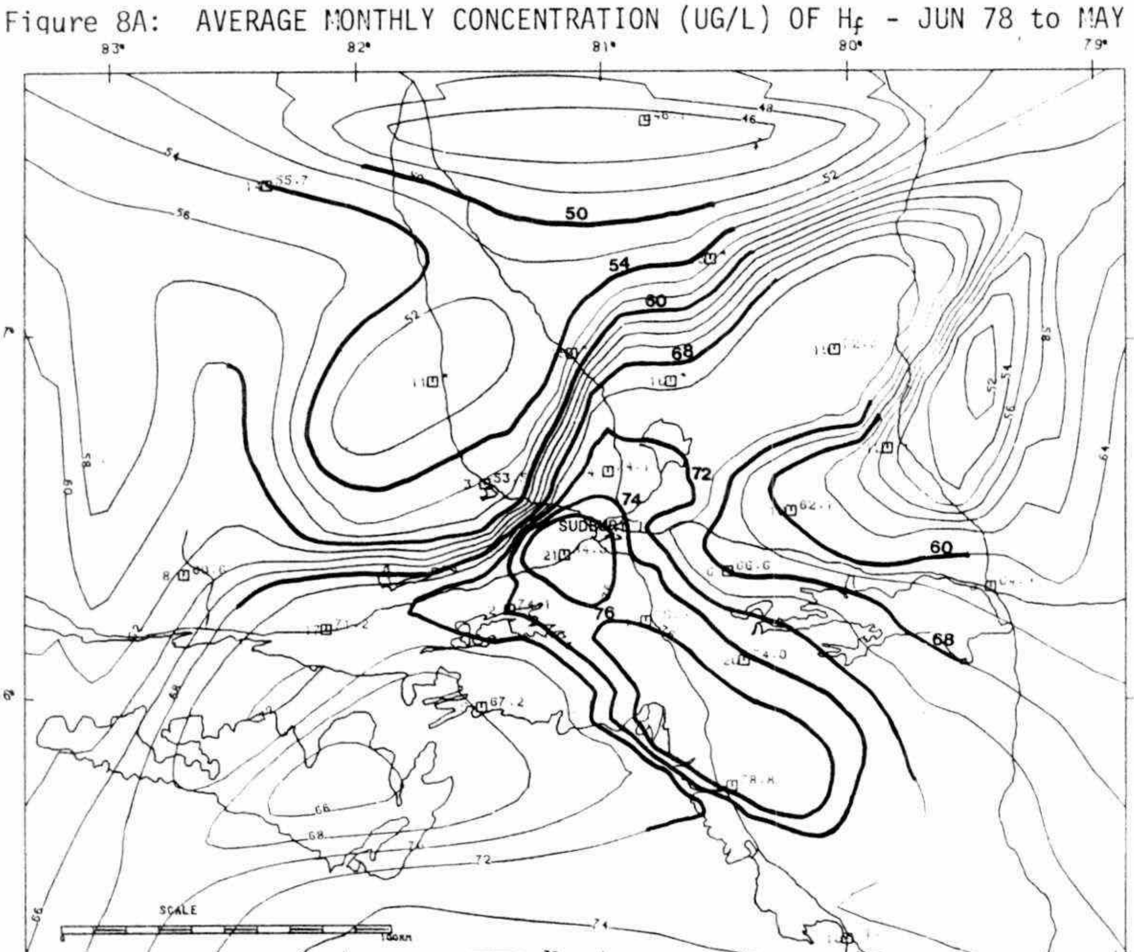


Figure 8B: AVERAGE MONTHLY CONCENTRATION (UG/L) OF H_f - JUN 79 to MAY 80

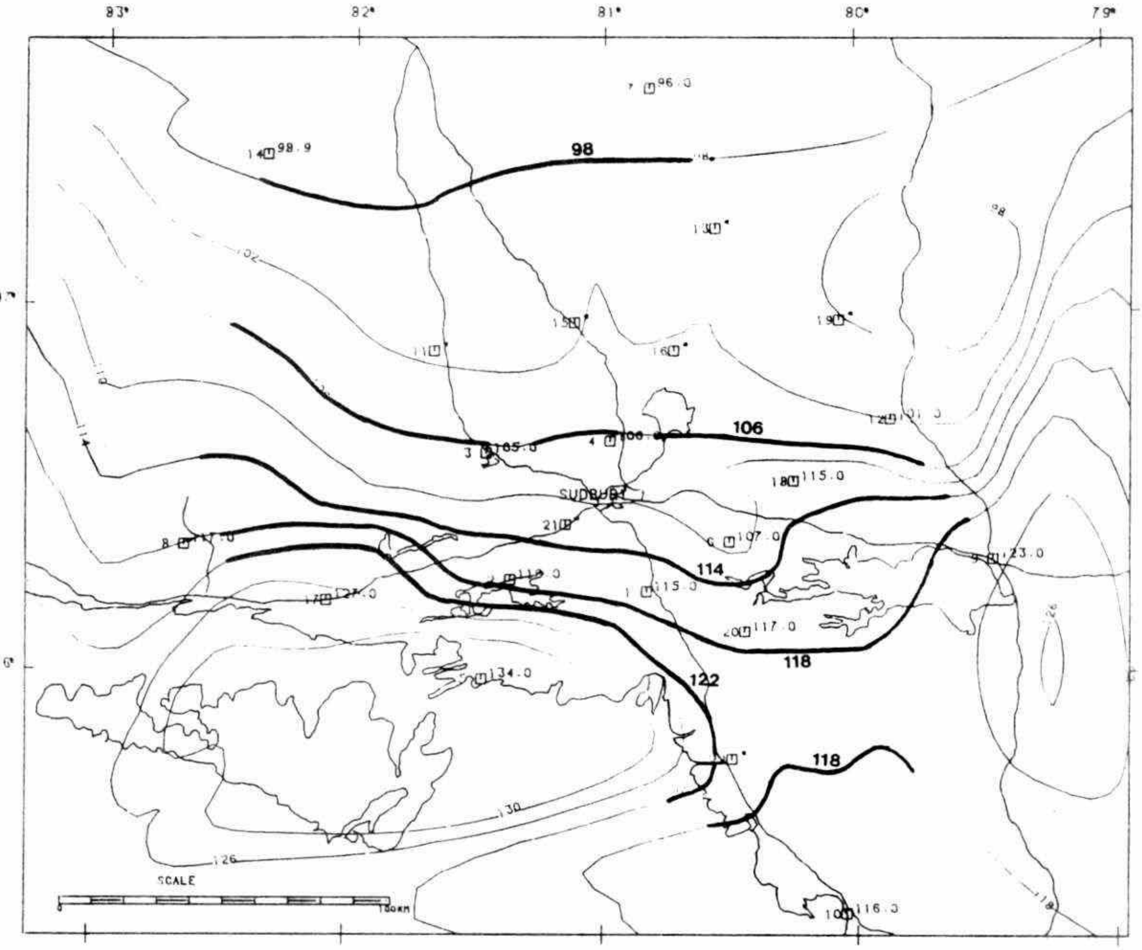


Figure 9a: AVERAGE MONTHLY CONCENTRATION (UG/L) OF H_t - JUN 78 TO MAY 79

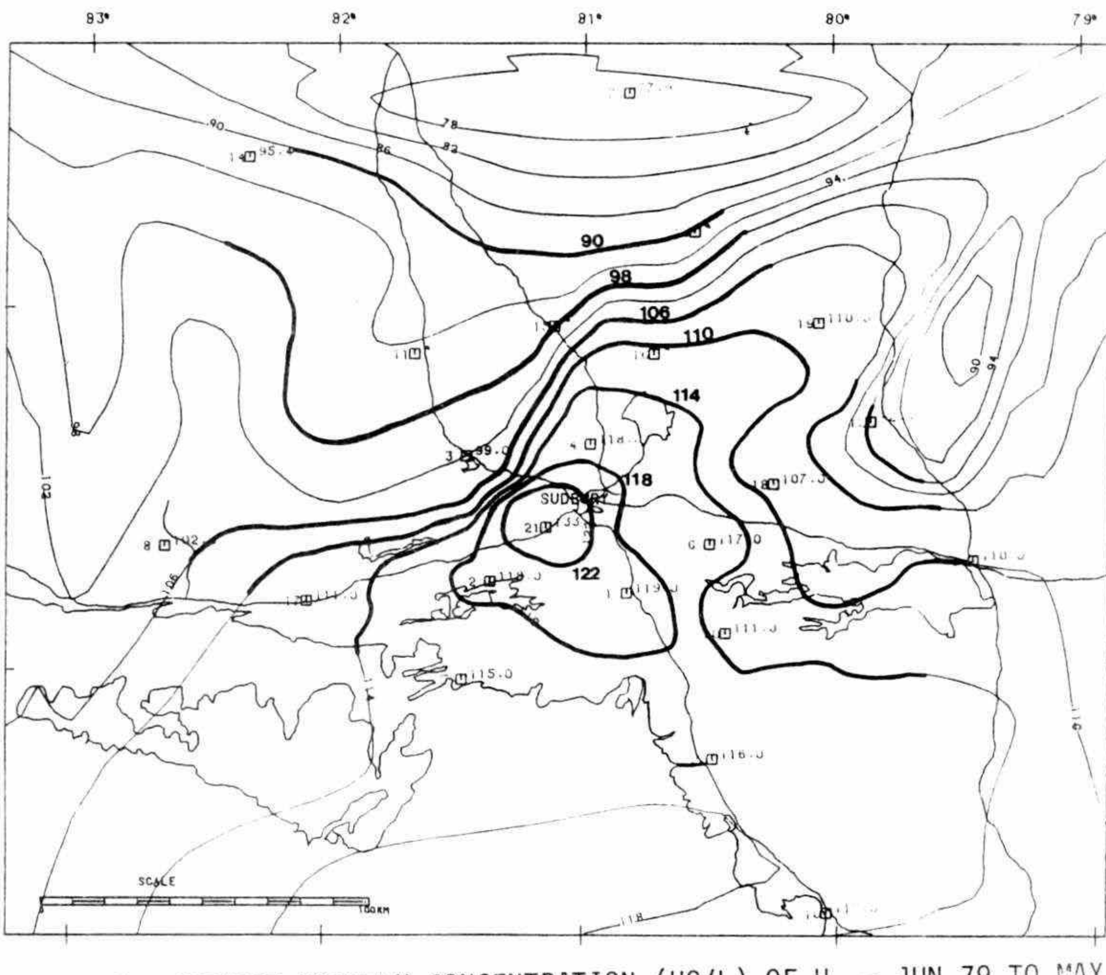


Figure 9b: AVERAGE MONTHLY CONCENTRATION (UG/L) OF H_t - JUN 79 TO MAY 80

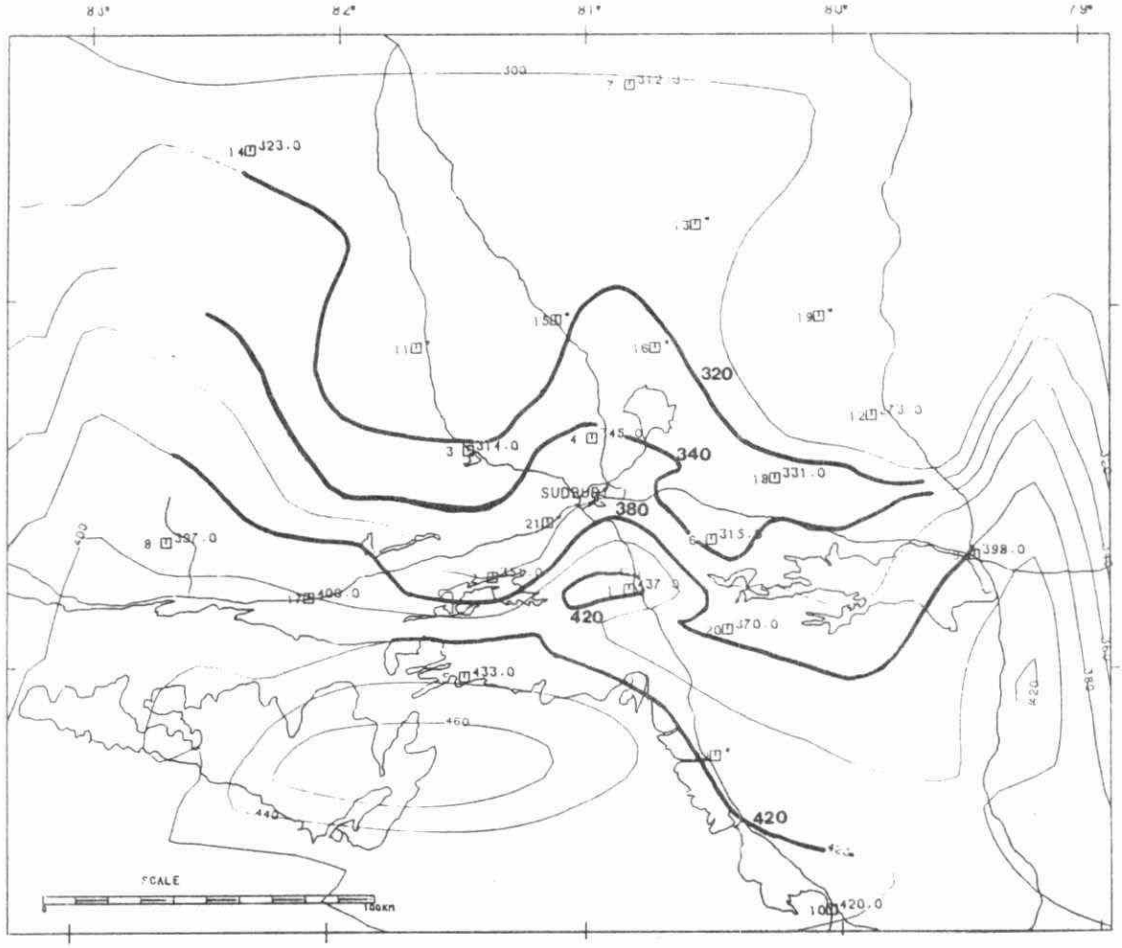


Figure 10a: AVERAGE MONTHLY CONCENTRATION (10 UG/L) OF SO4 - JUN 78 to MAY 79

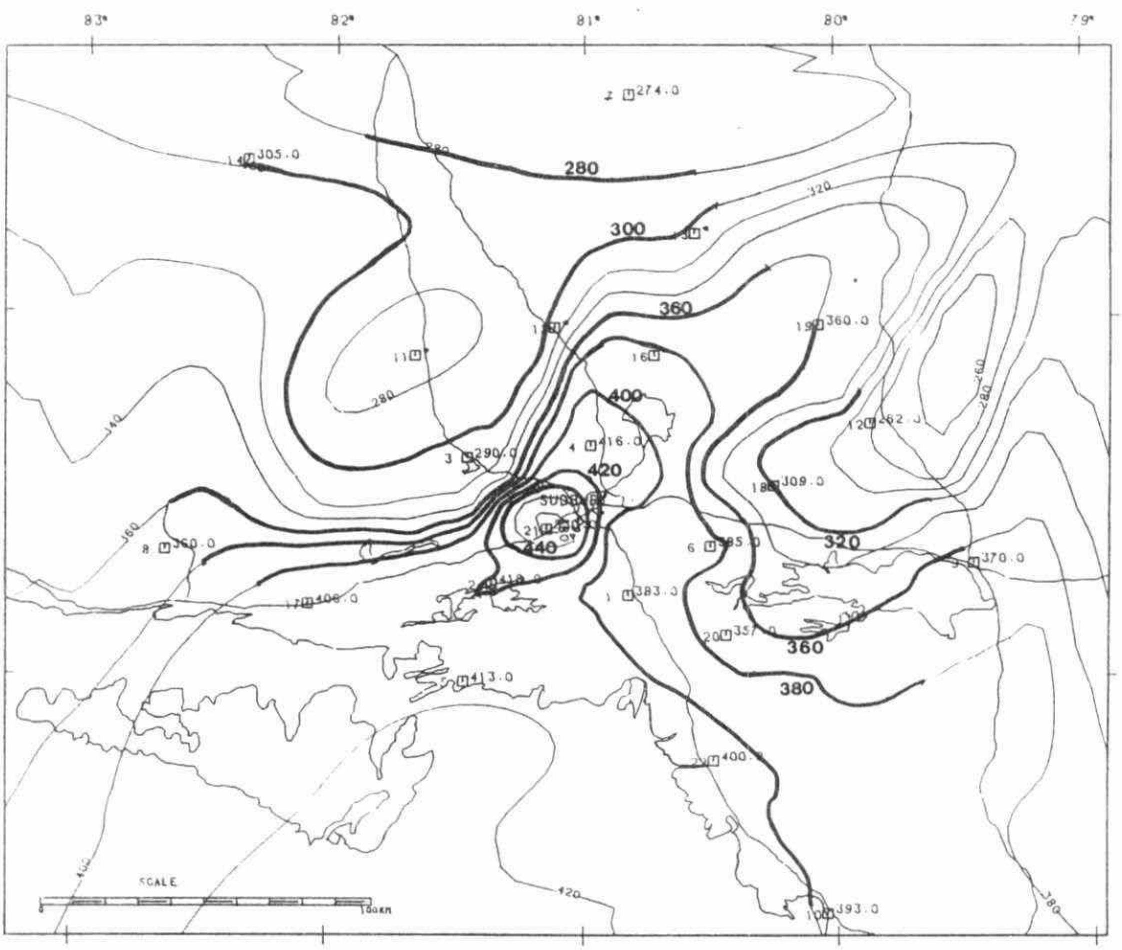


Figure 10b: AVERAGE MONTHLY CONCENTRATION (10UG/L) OF SO4 - JUN 79 TO MAY 80

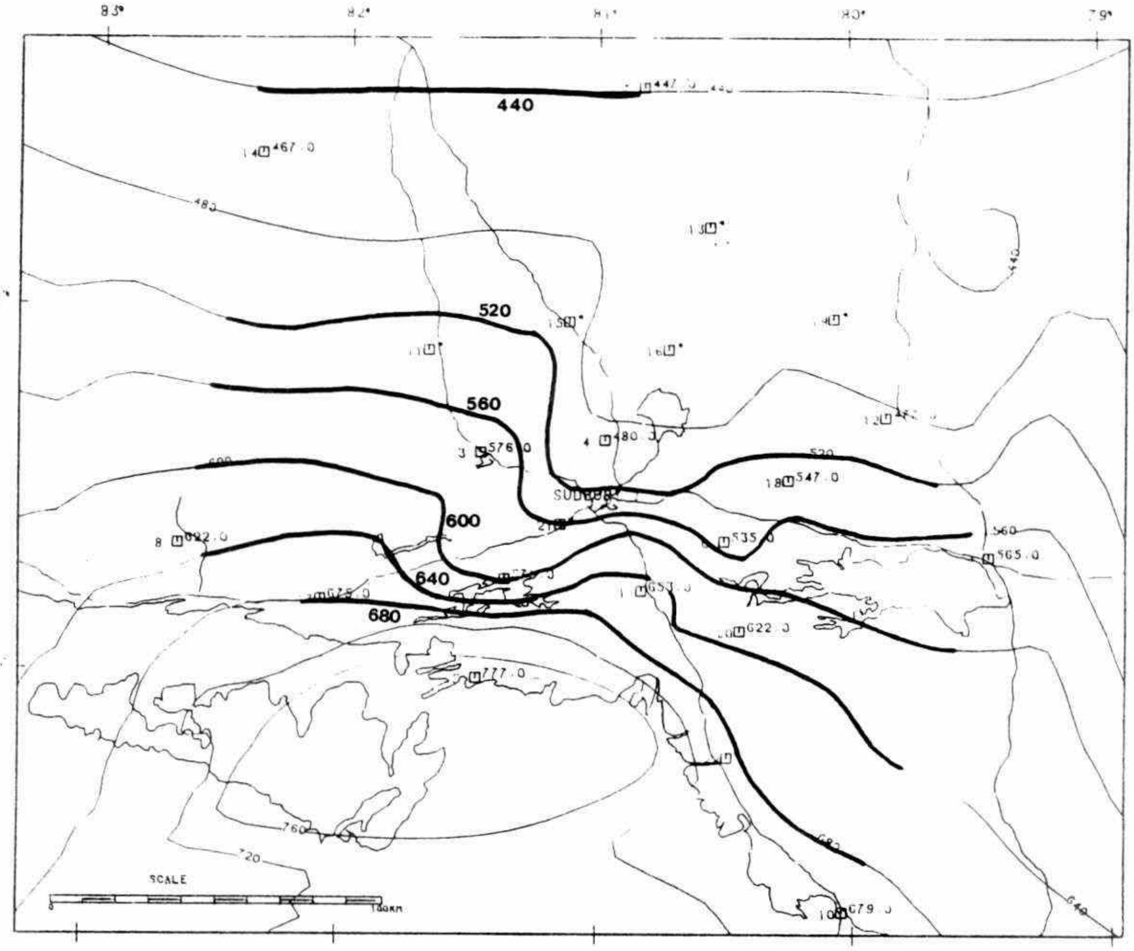


Figure 11a: AVERAGE MONTHLY CONCENTRATION (UG/L) OF N-NO3 - JUN 78 TO MAY 79

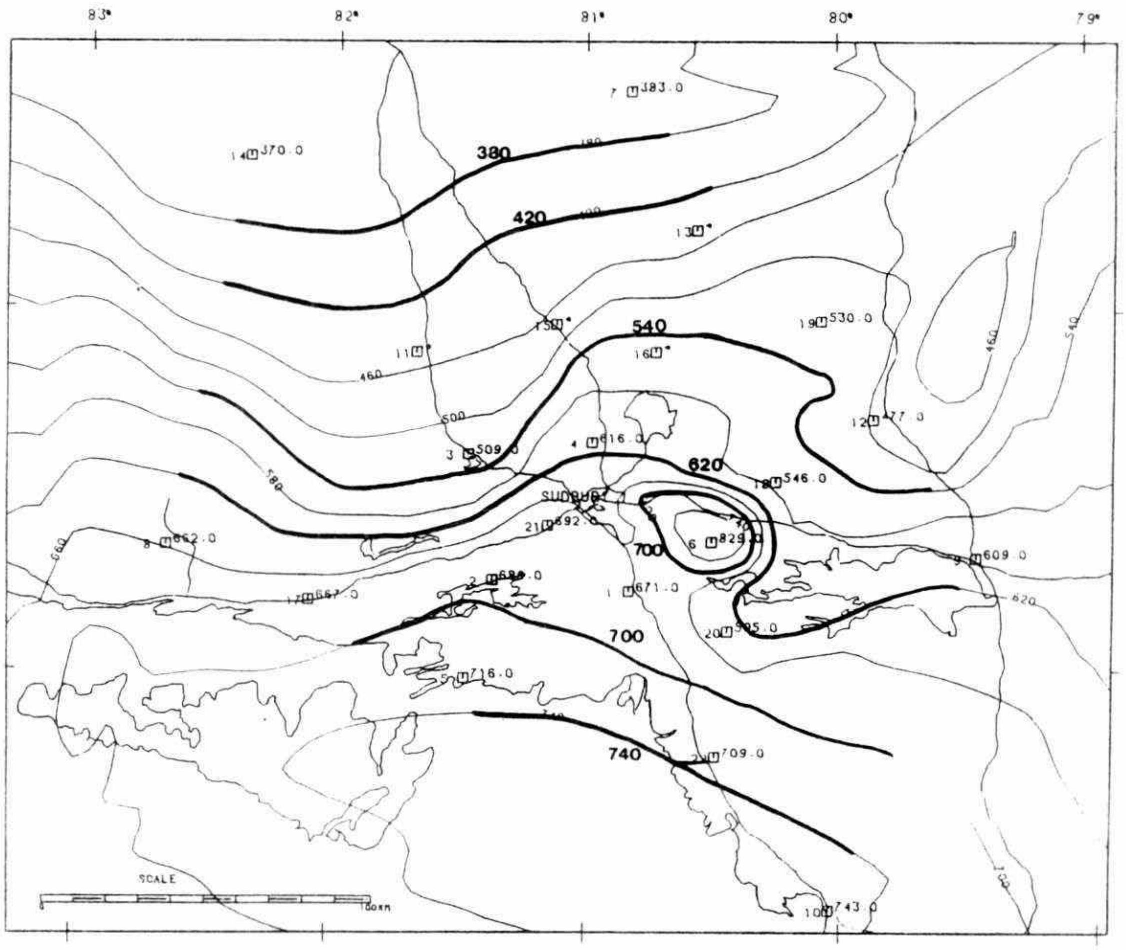


Figure 11b: AVERAGE MONTHLY CONCENTRATION(UG/L) OF N-NO3 - JUN 79 TO MAY 80

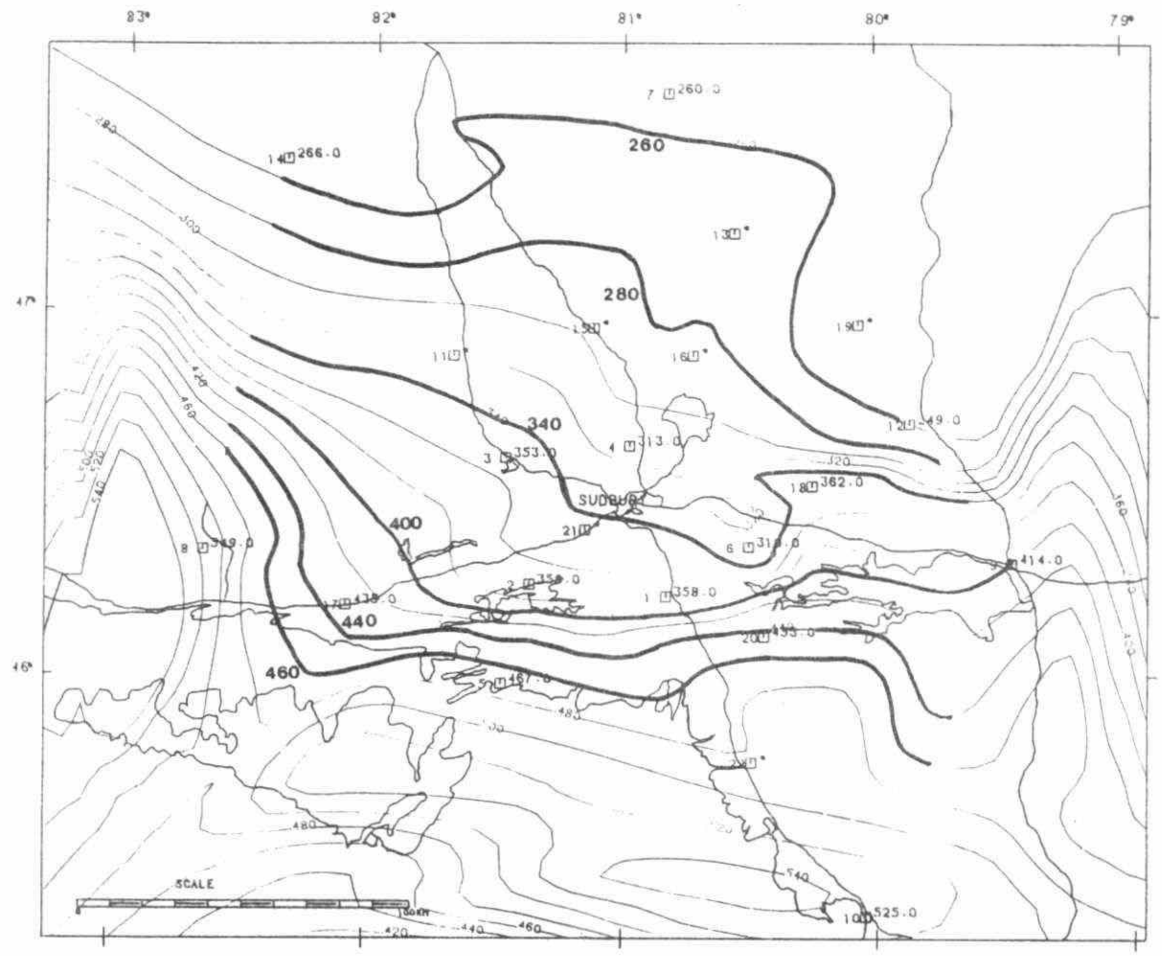


Figure 12a: AVERAGE MONTHLY CONCENTRATION (UG/L) OF N-NH4 - JUN 78 TO MAY 7

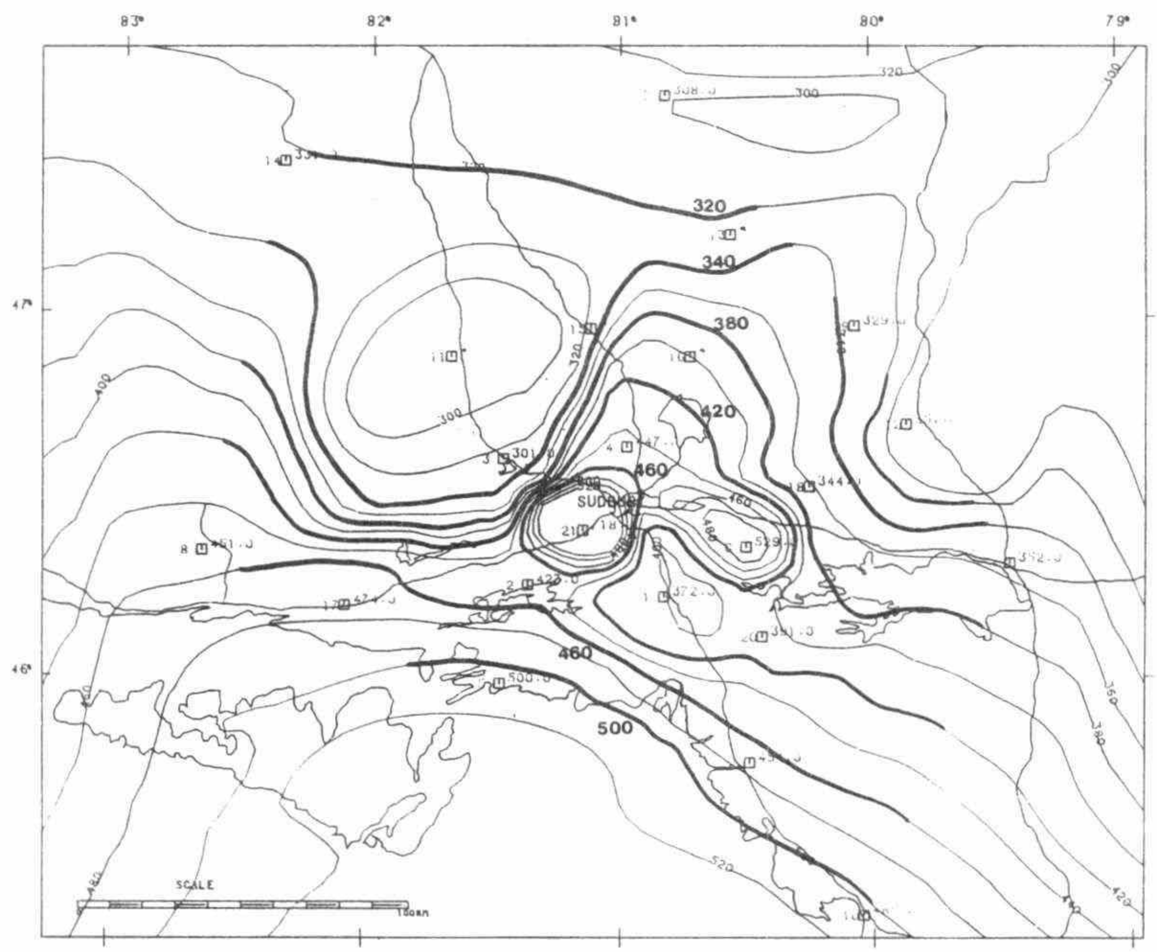


Figure 12b: AVERAGE MONTHLY CONCENTRATION (UG/L) OF N-NH4 - JUN 79 TO MAY 80

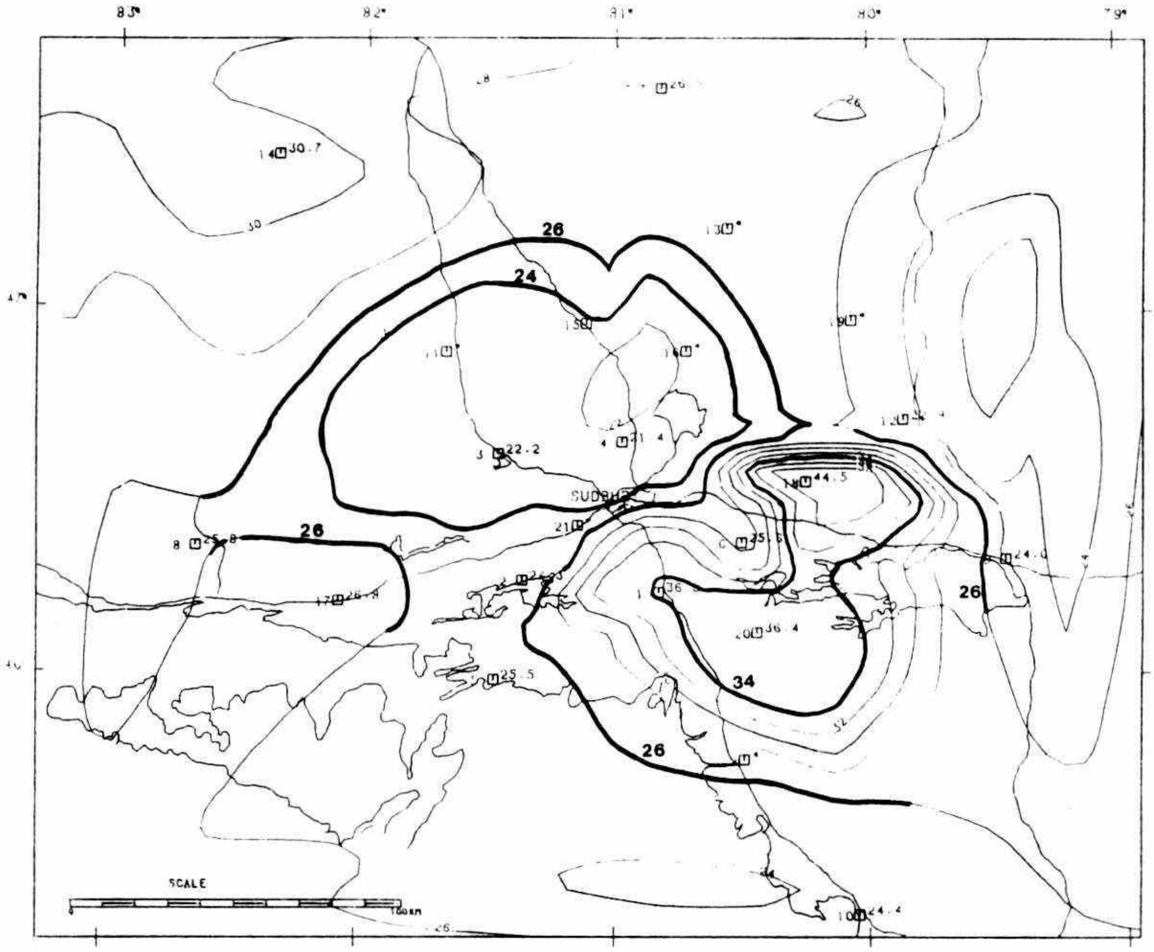


Figure 13a: AVERAGE MONTHLY CONCENTRATION(UG/L) OF F - JUN 78 to MAY 79

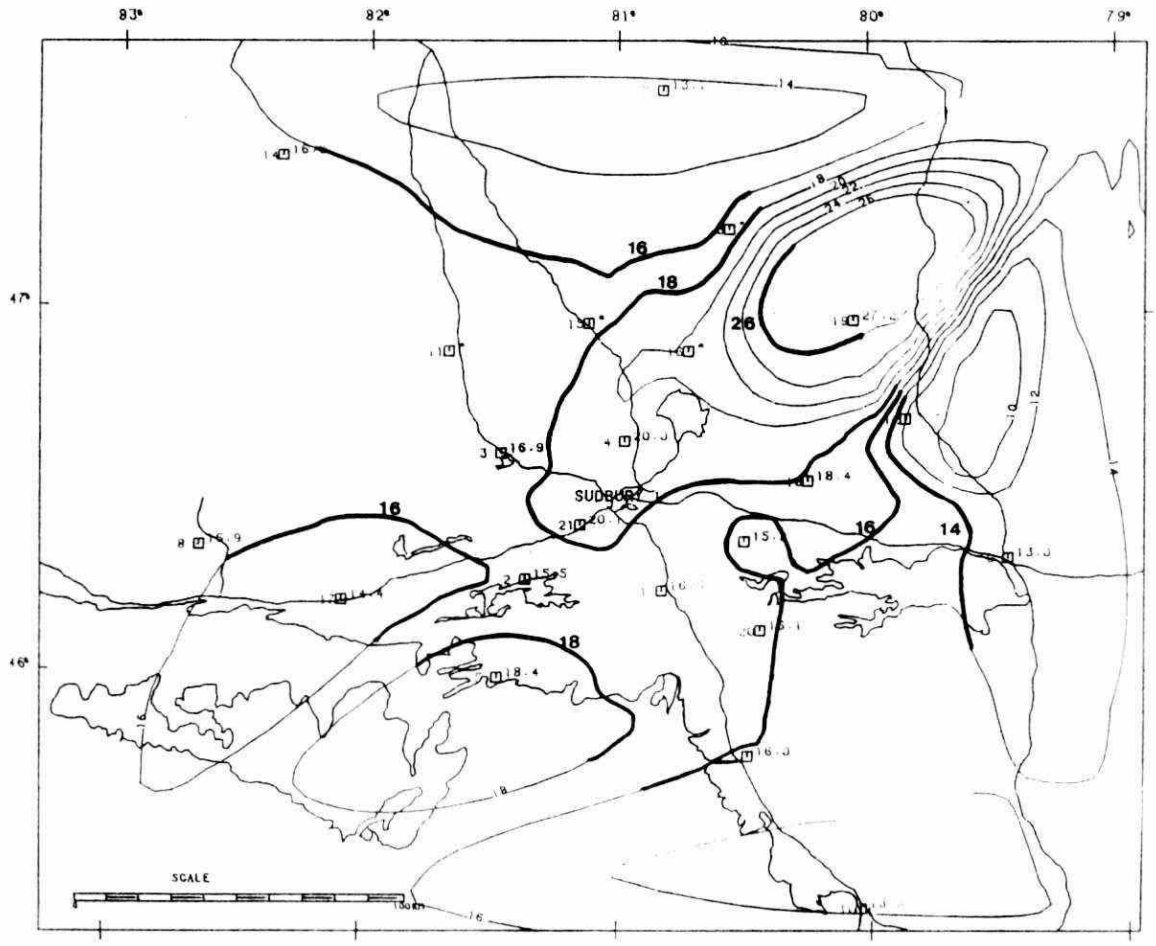


Figure 13b: AVERAGE MONTHLY CONCENTRATION(UG/L) OF F - JUN 79 TO MAY 80

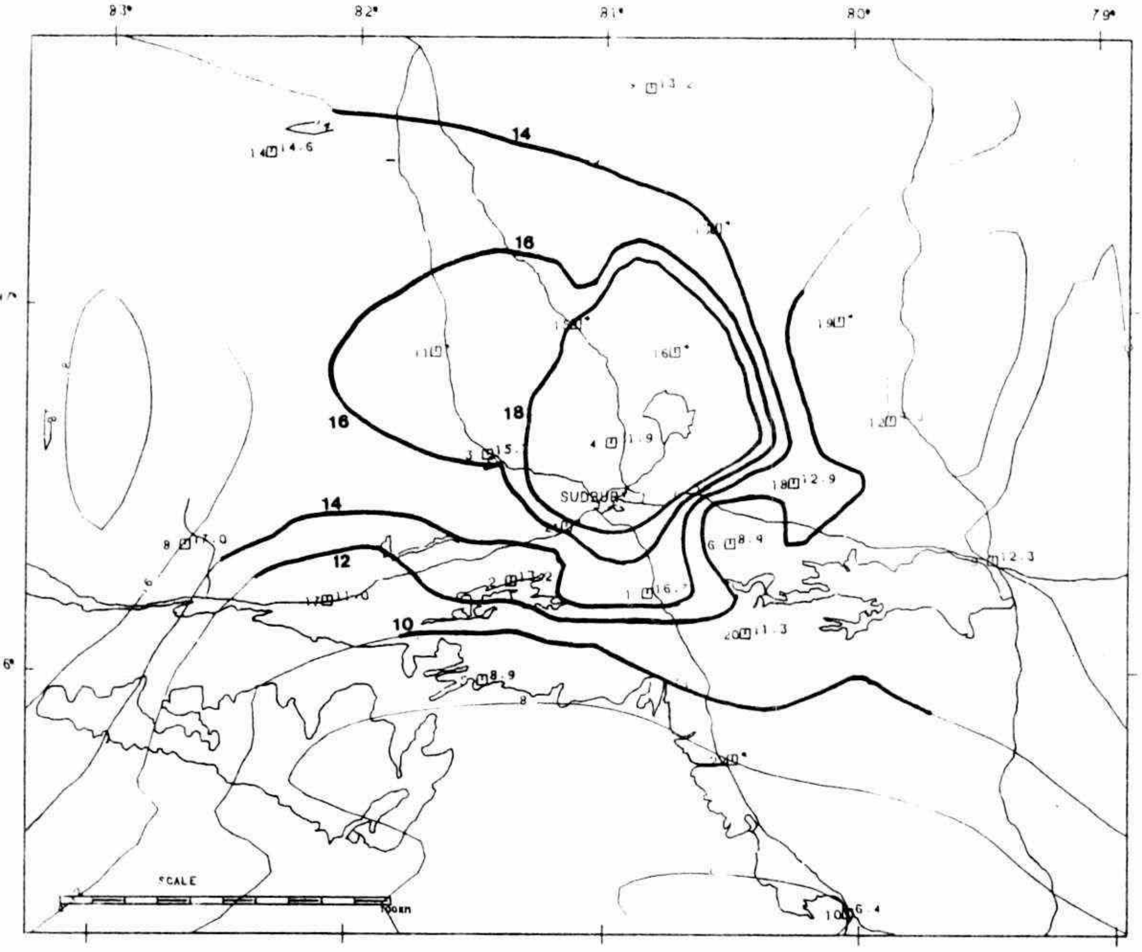


Figure 14a: AVERAGE MONTHLY CONCENTRATION (UG/10L) OF Ni - JUN 78 TO MAY 79

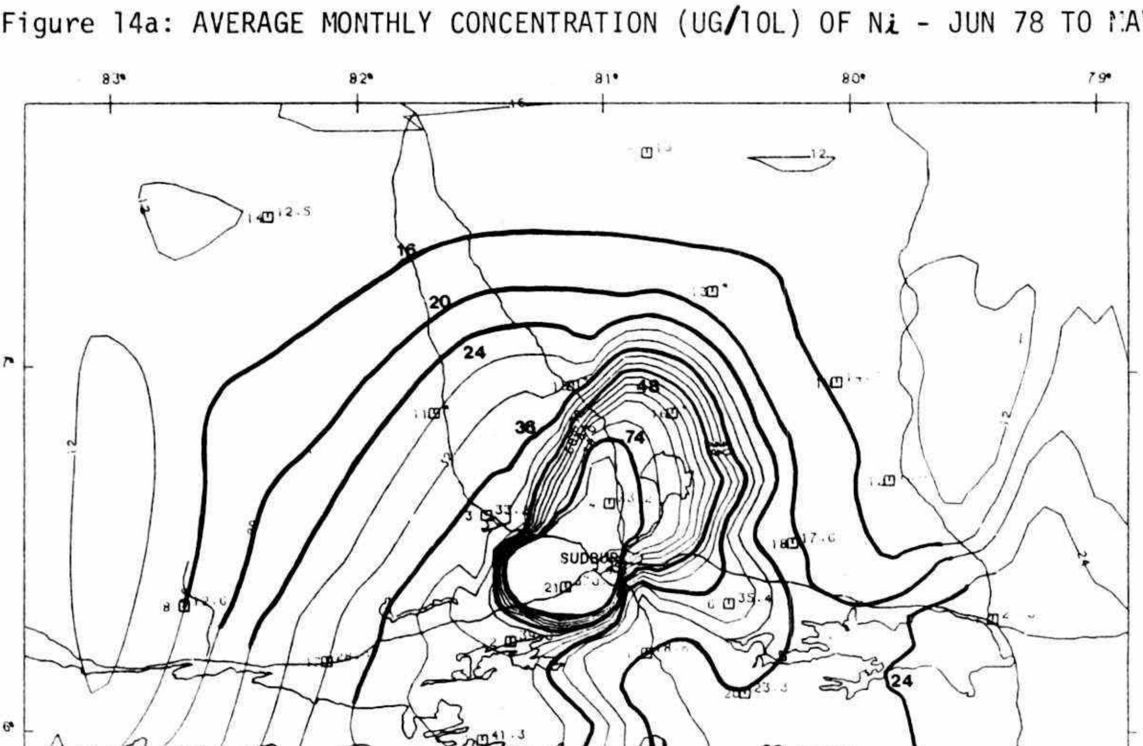


Figure 14b: AVERAGE MONTHLY CONCENTRATION(UG/10L) OF Ni - JUN 79 to MAY 80

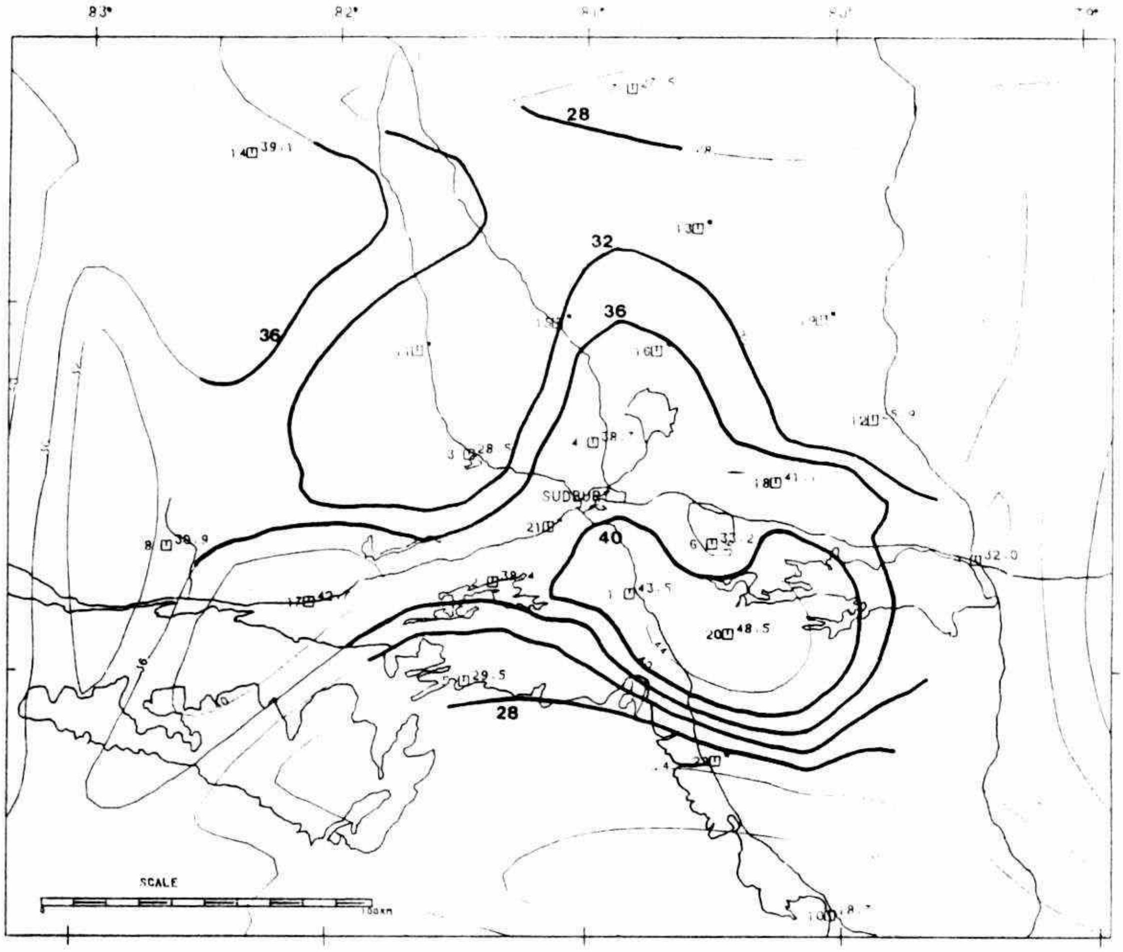


Figure 15a: AVERAGE MONTHLY CONCENTRATION(UG/10L) OF CU - JUN 78 TO MAY 79

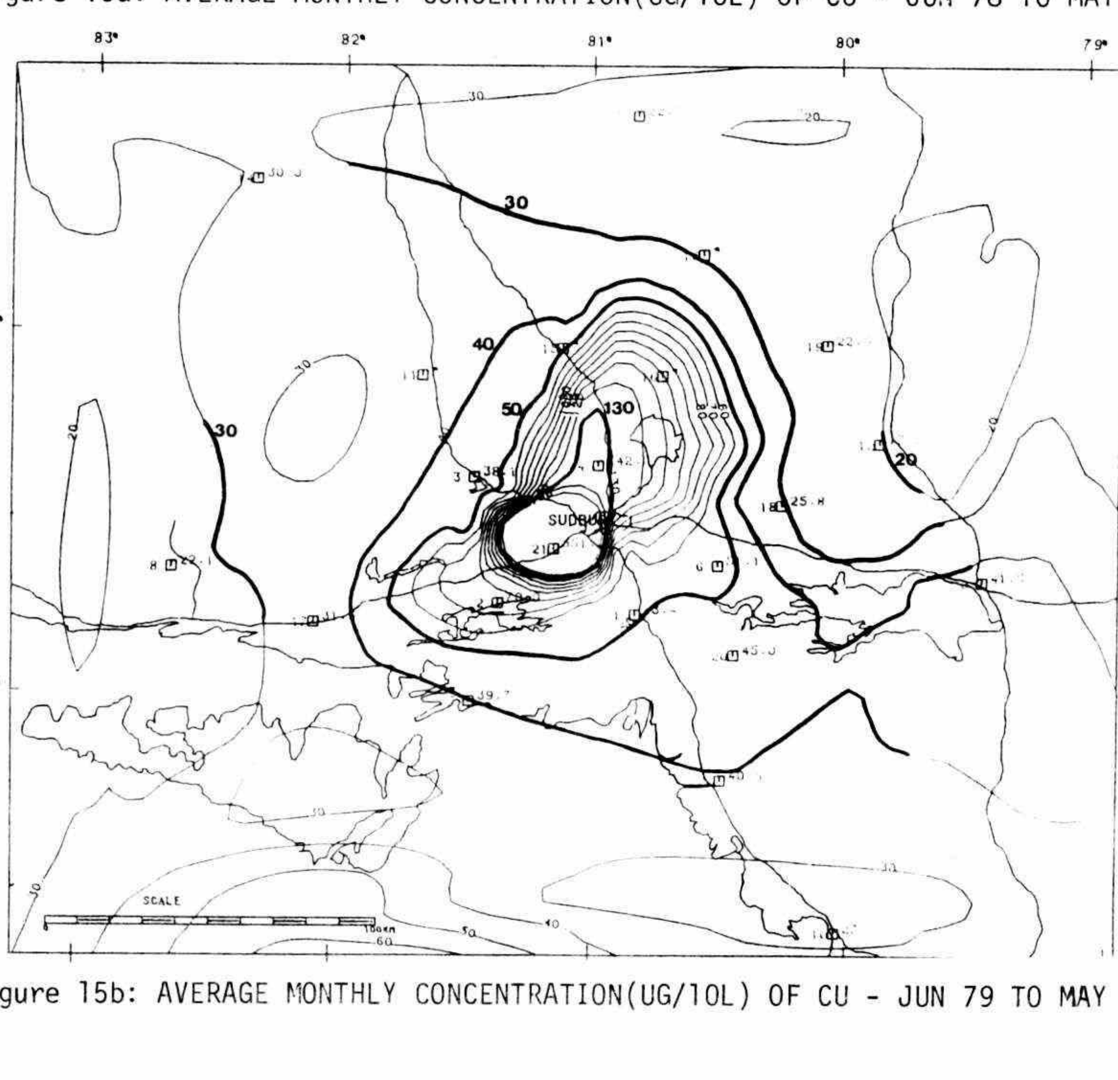


Figure 15b: AVERAGE MONTHLY CONCENTRATION(UG/10L) OF CU - JUN 79 TO MAY 80

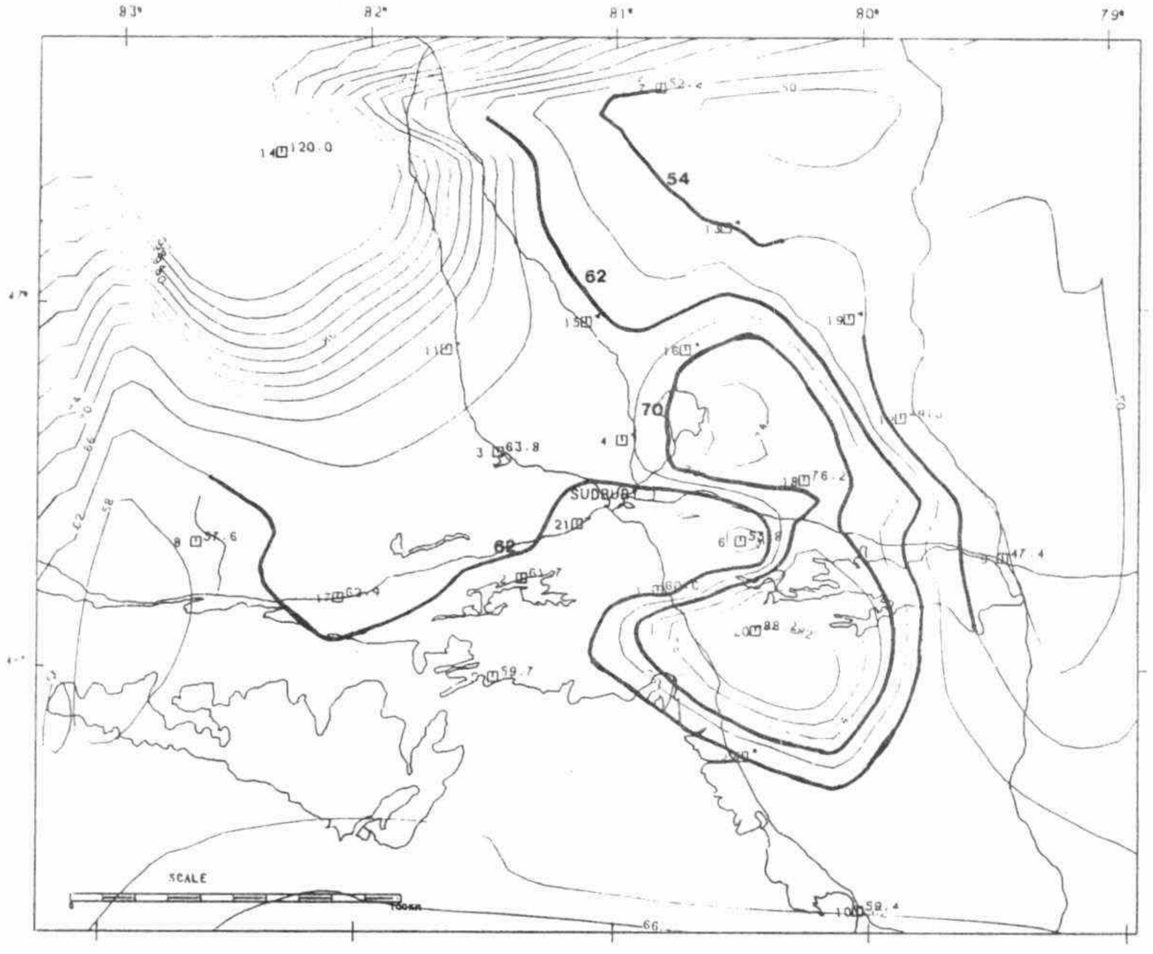


Figure 16a: AVERAGE MONTHLY CONCENTRATION(UG/L) OF FE - JUN 78 TO MAY 79

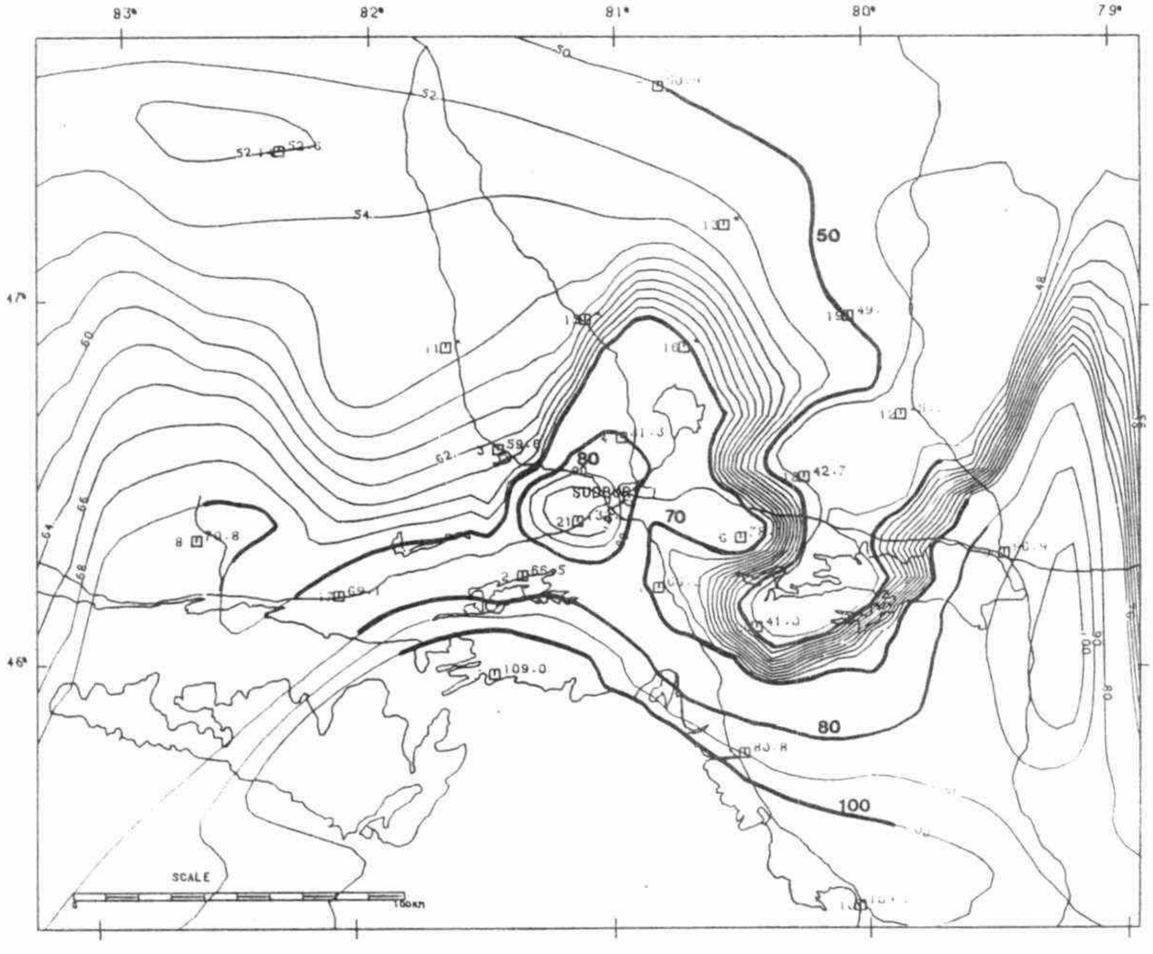


Figure 16b: AVERAGE MONTHLY CONCENTRATION(UG/L) OF FE - JUN 79 TO MAY 80

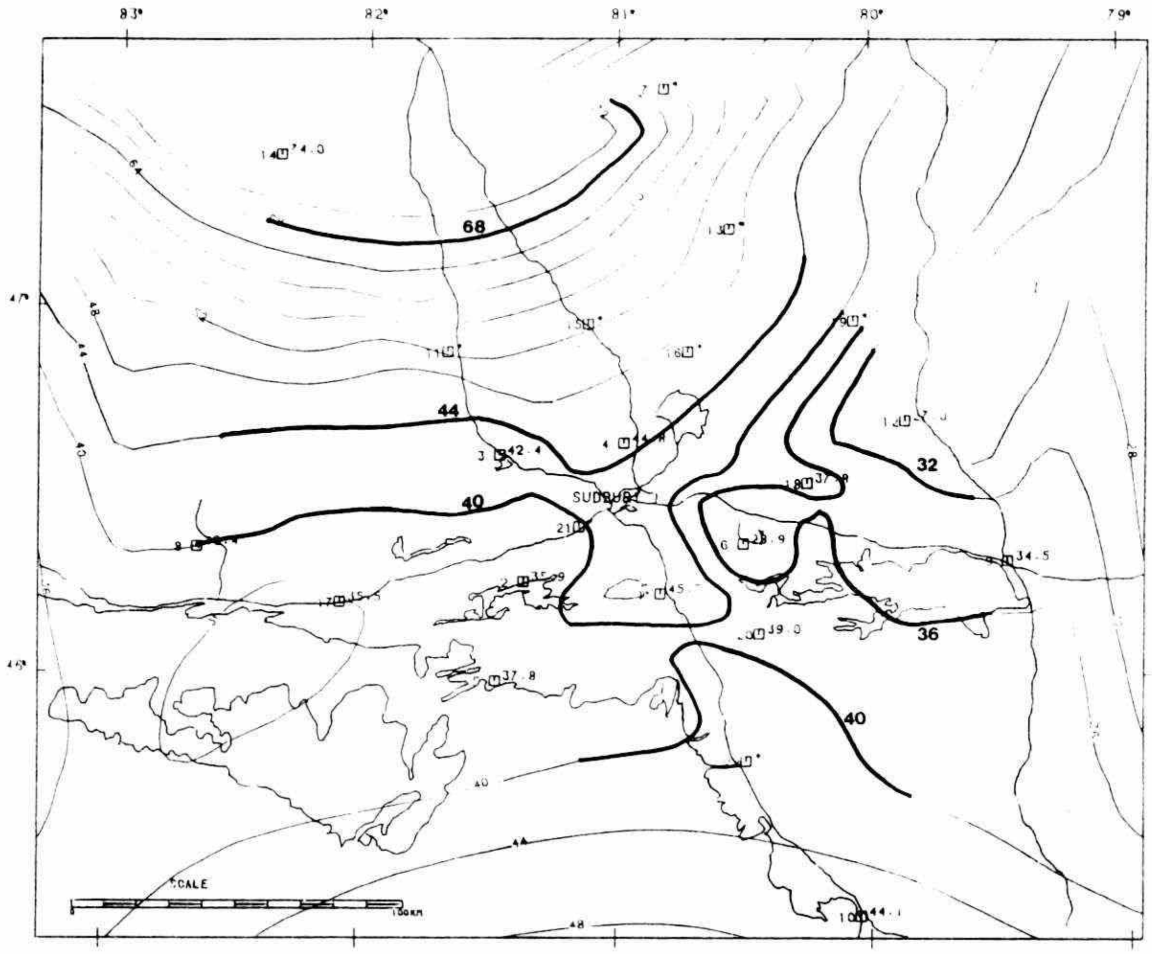


Figure 17a: AVERAGE MONTHLY CONCENTRATION(UG/L) OF AL - JUN 78 TO MAY 79

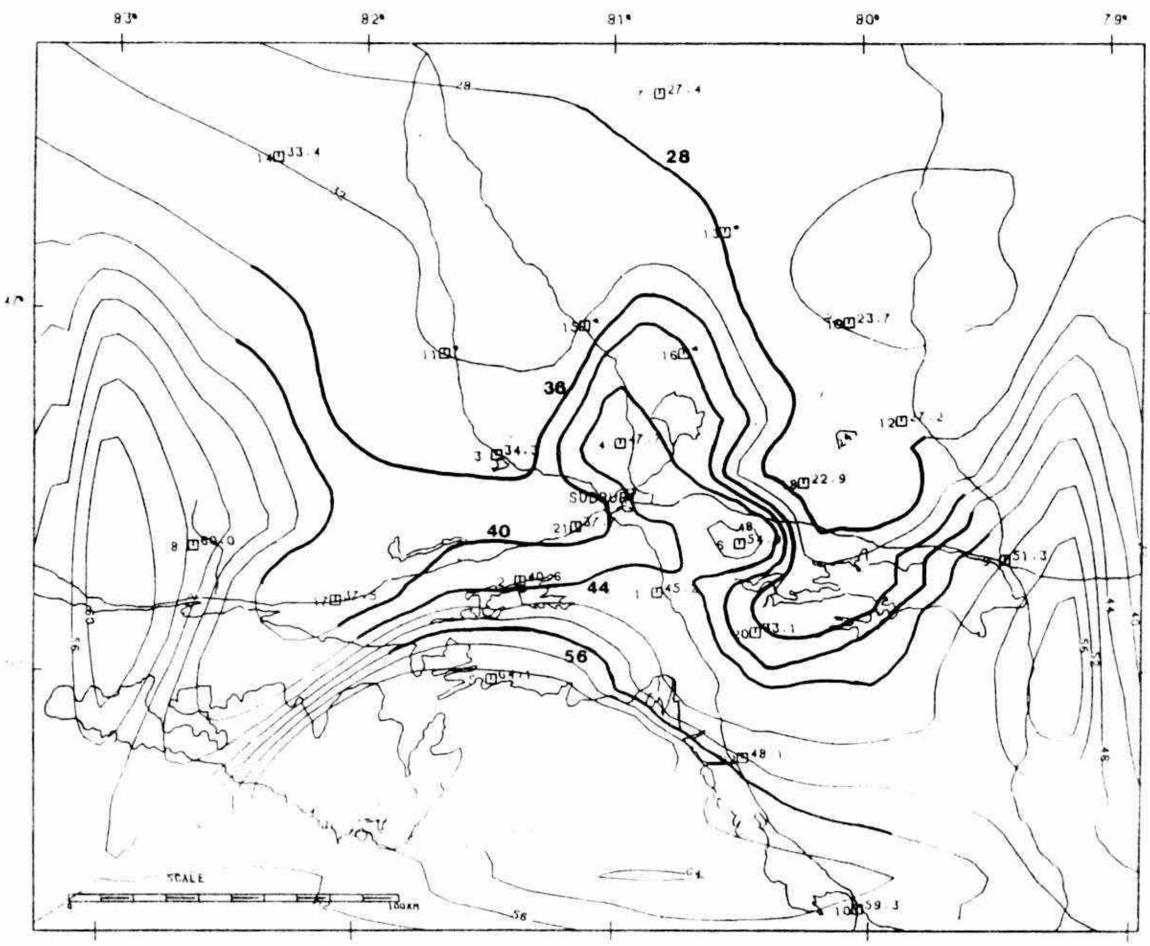


Figure 17b: AVERAGE MONTHLY CONCENTRATION (UG/L) OF AL - JUN 79 TO MAY 80

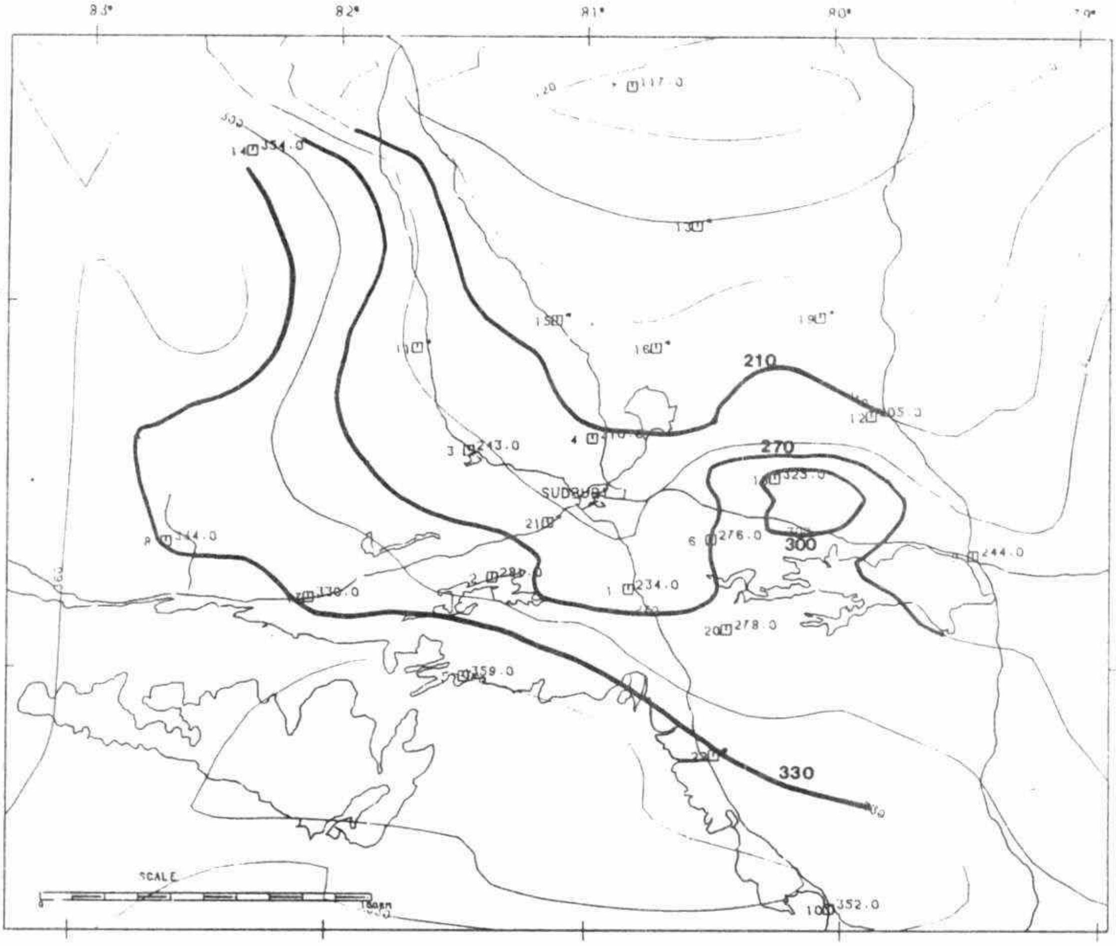


Figure 18a: AVERAGE MONTHLY CONCENTRATION(UG/L) OF CA - JUN 78 TO MAY 7)

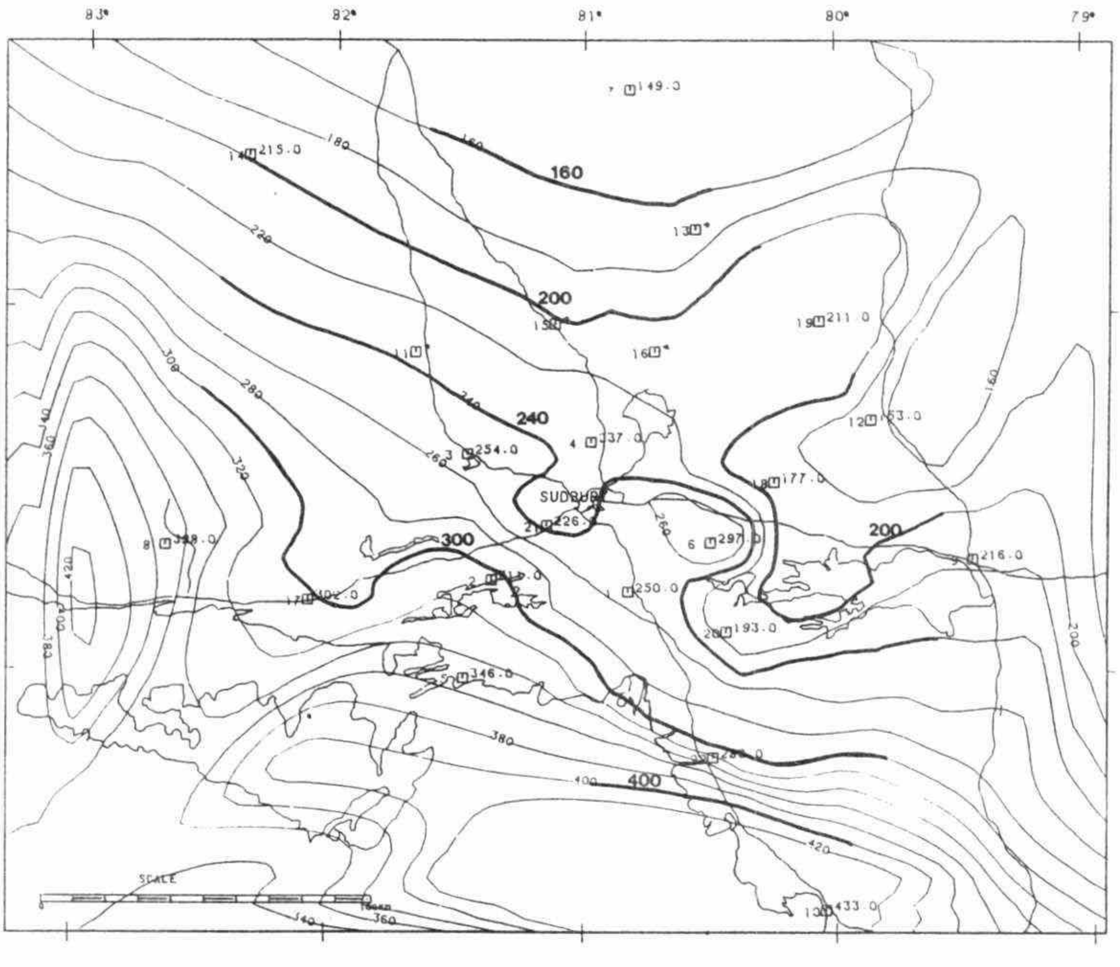


Figure 18b: AVERAGE MONTHLY CONCENTRATION (UG/L) OF CA - JUN 79 TO MAY 8)

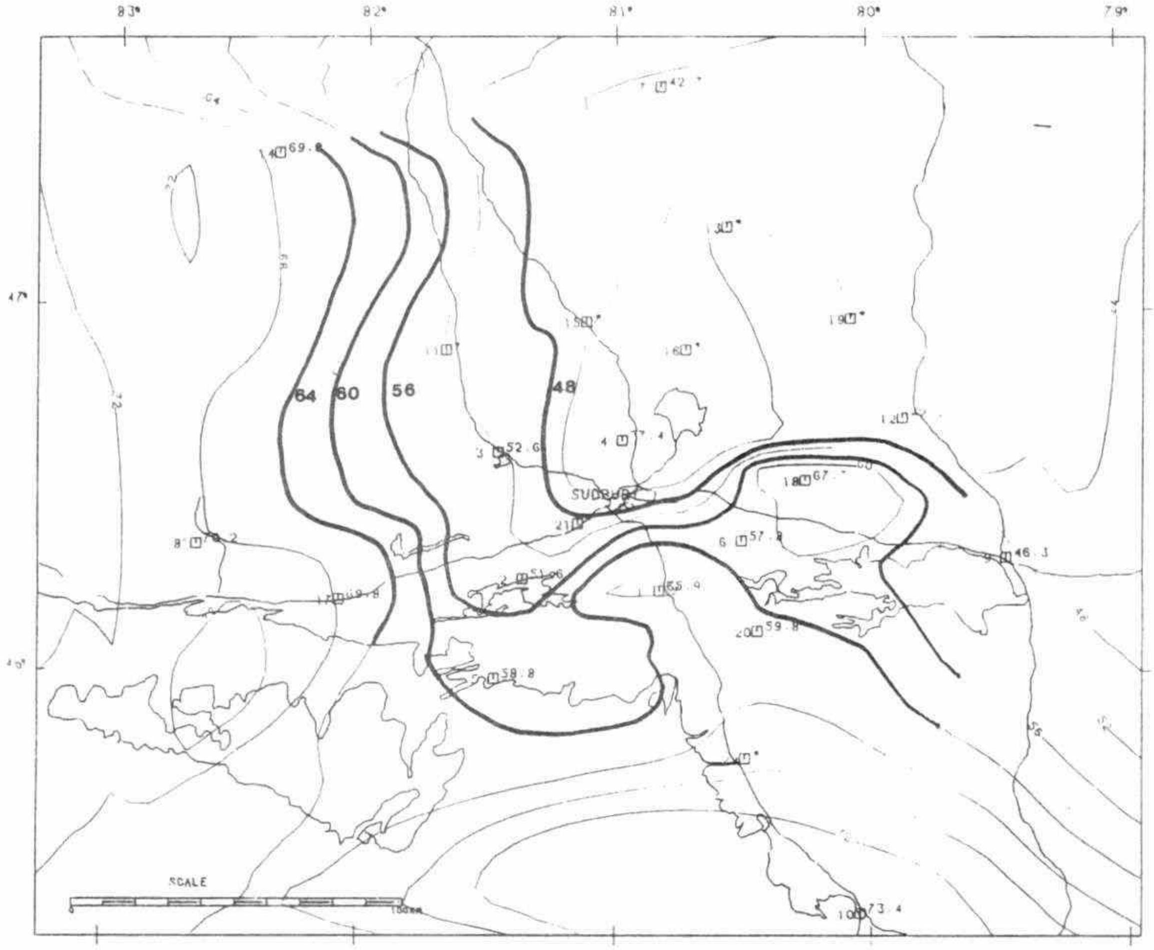


Figure 19a: AVERAGE MONTHLY CONCENTRATION (UG/L) OF MG - JUN 78 TO MAY 79

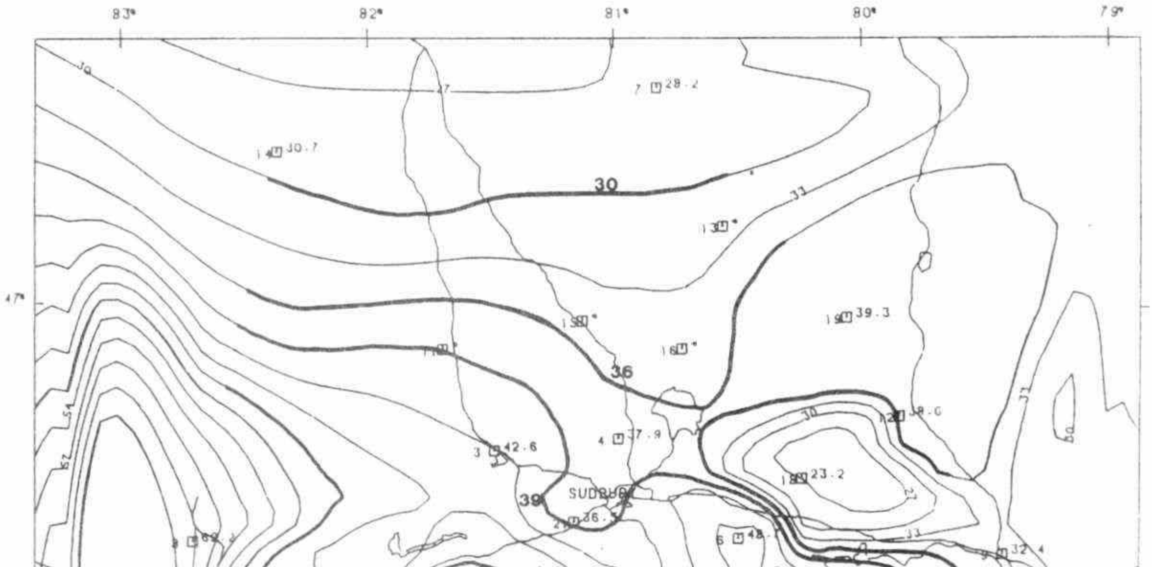


Figure 19b: AVERAGE MONTHLY CONCENTRATION(UG/L) OF MG - JUN 79 TO MAY 80

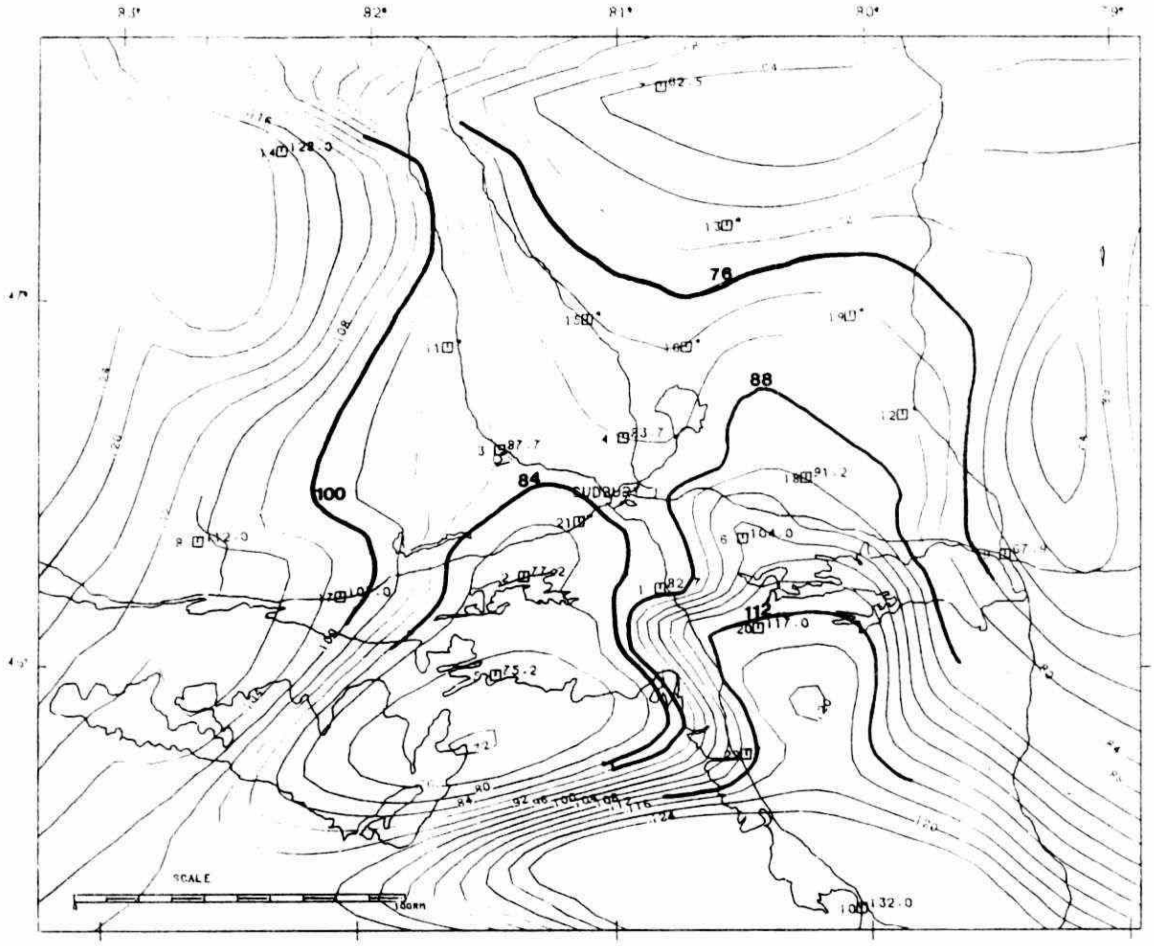


Figure 20a: AVERAGE MONTHLY CONCENTRATION(UG/L) OF K - JUN 78 TO MAY 79

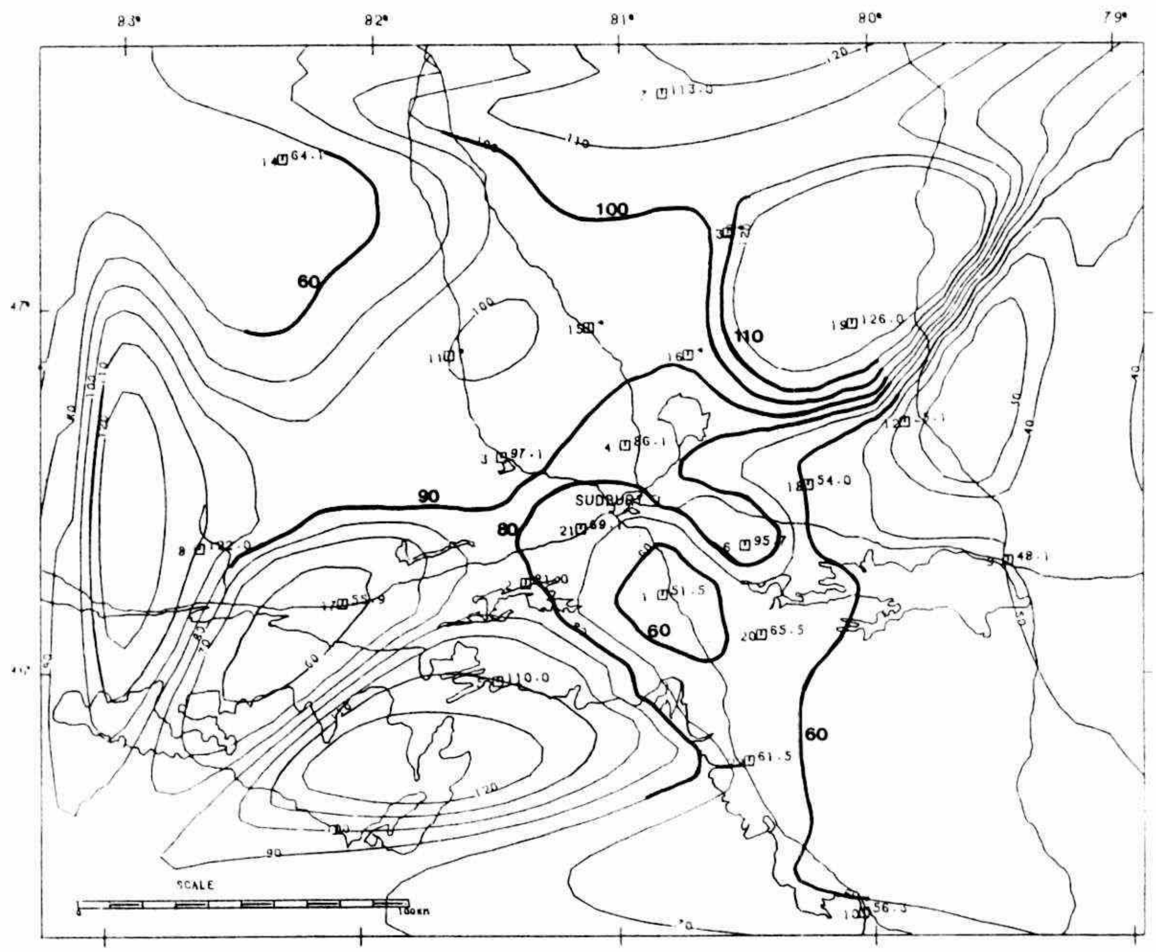


Figure 20b: AVERAGE MONTHLY CONCENTRATION(UG/L) OF K - JUN 79 TO MAY 80

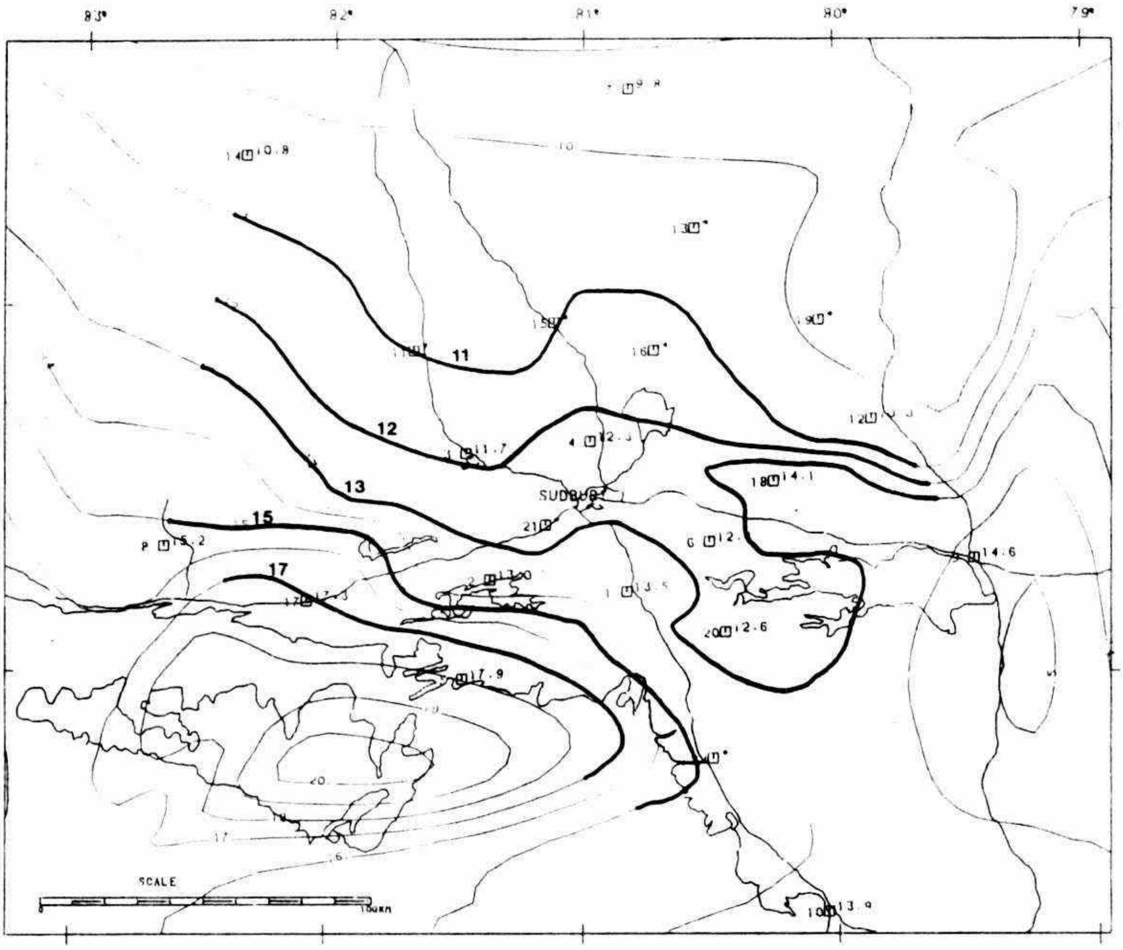


Figure 21a: AVERAGE MONTHLY CONCENTRATION(UG/L) OF PB - JUN 78 TO MAY 79

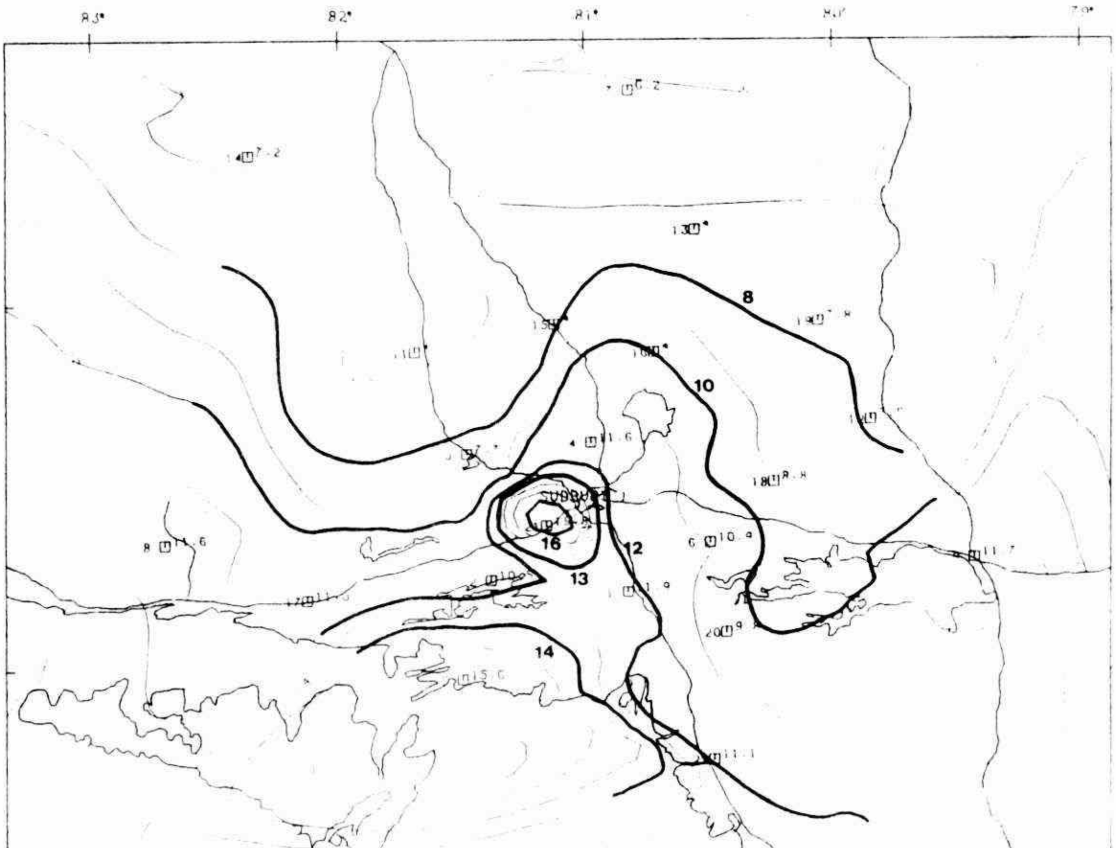


Figure 21b: AVERAGE MONTHLY CONCENTRATION(UG/L) OF PB - JUN 79 TO MAY 80

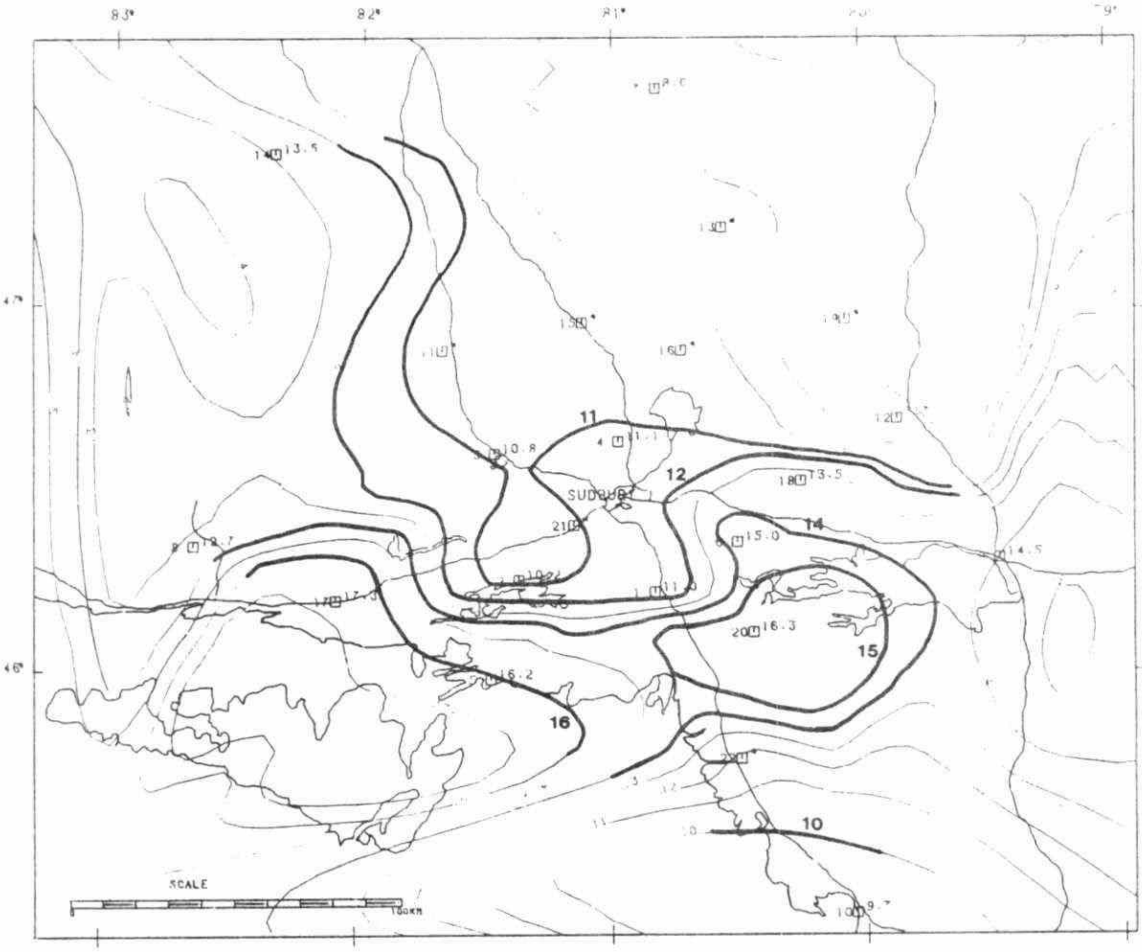


Figure: 22a: AVERAGE MONTHLY CONCENTRATION(UG/L) OF ZN - JUN 78 TO MAY 79

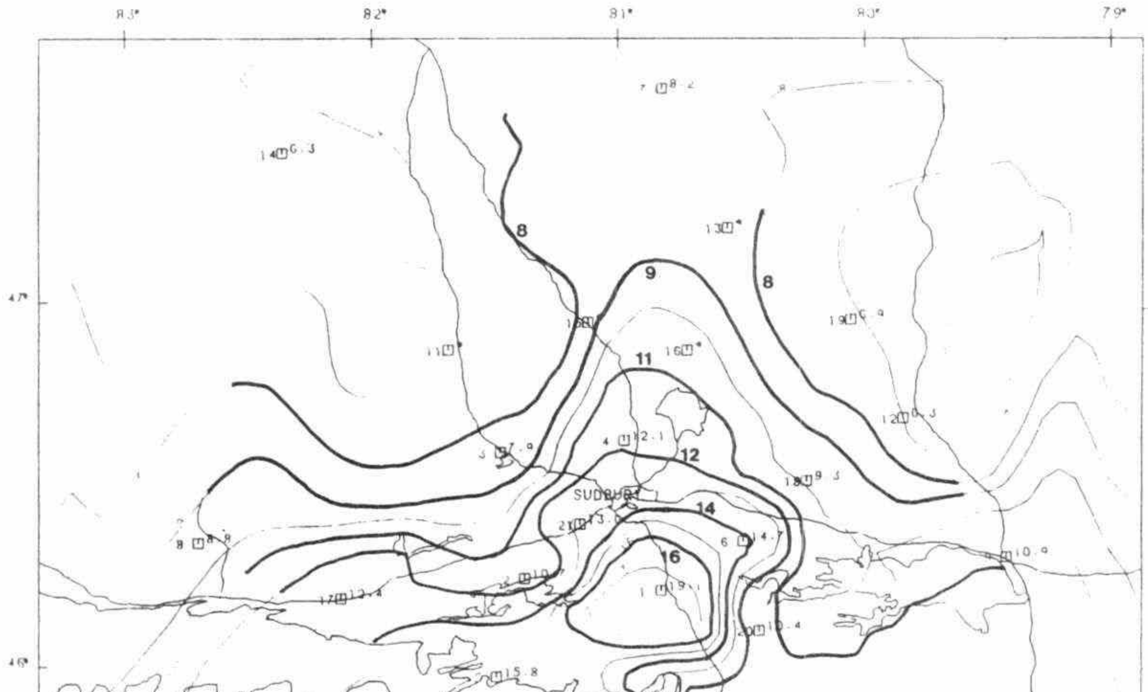


Figure 22b: AVERAGE MONTHLY CONCENTRATION(UG/L) OF ZN - JUN 79 TO MAY 80

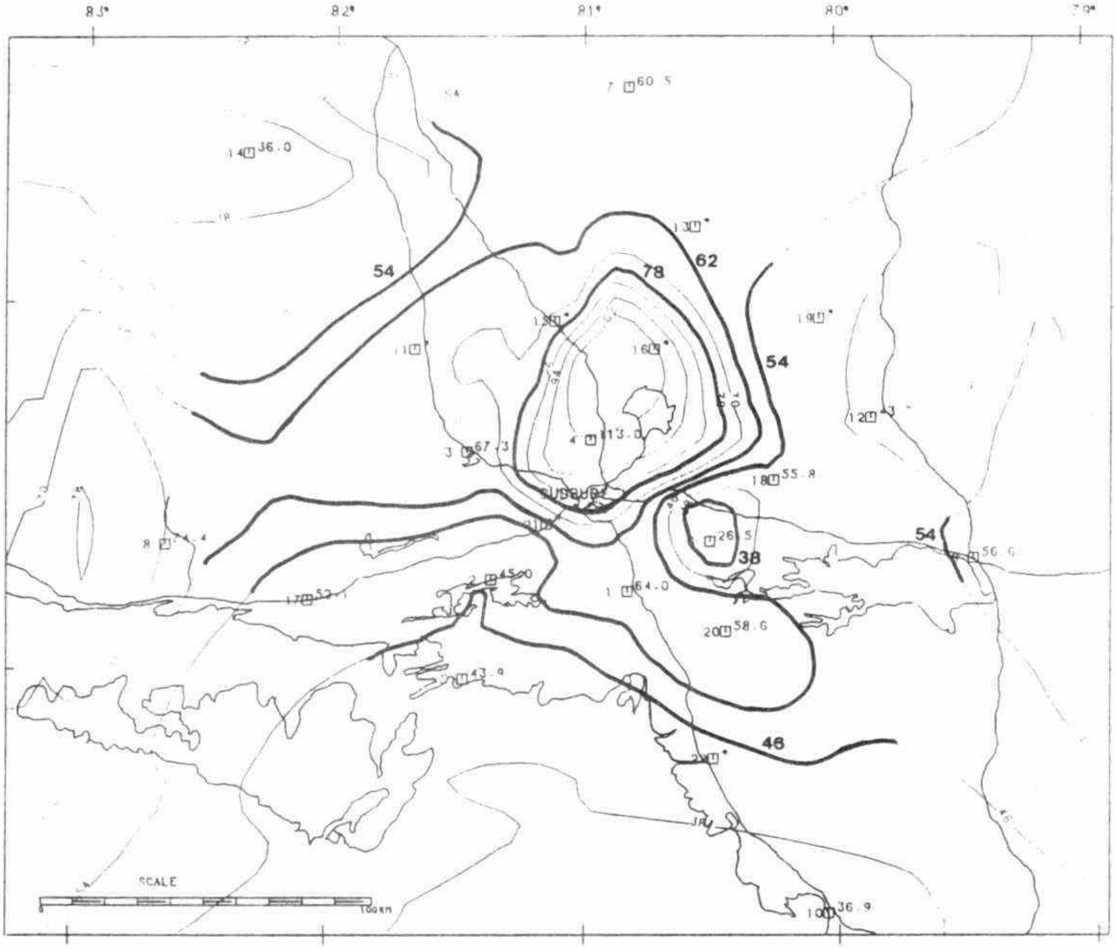


Figure 23a: AVERAGE MONTHLY CONCENTRATION (UG/100 L) OF CR - JUNE 78 TO MAY 79

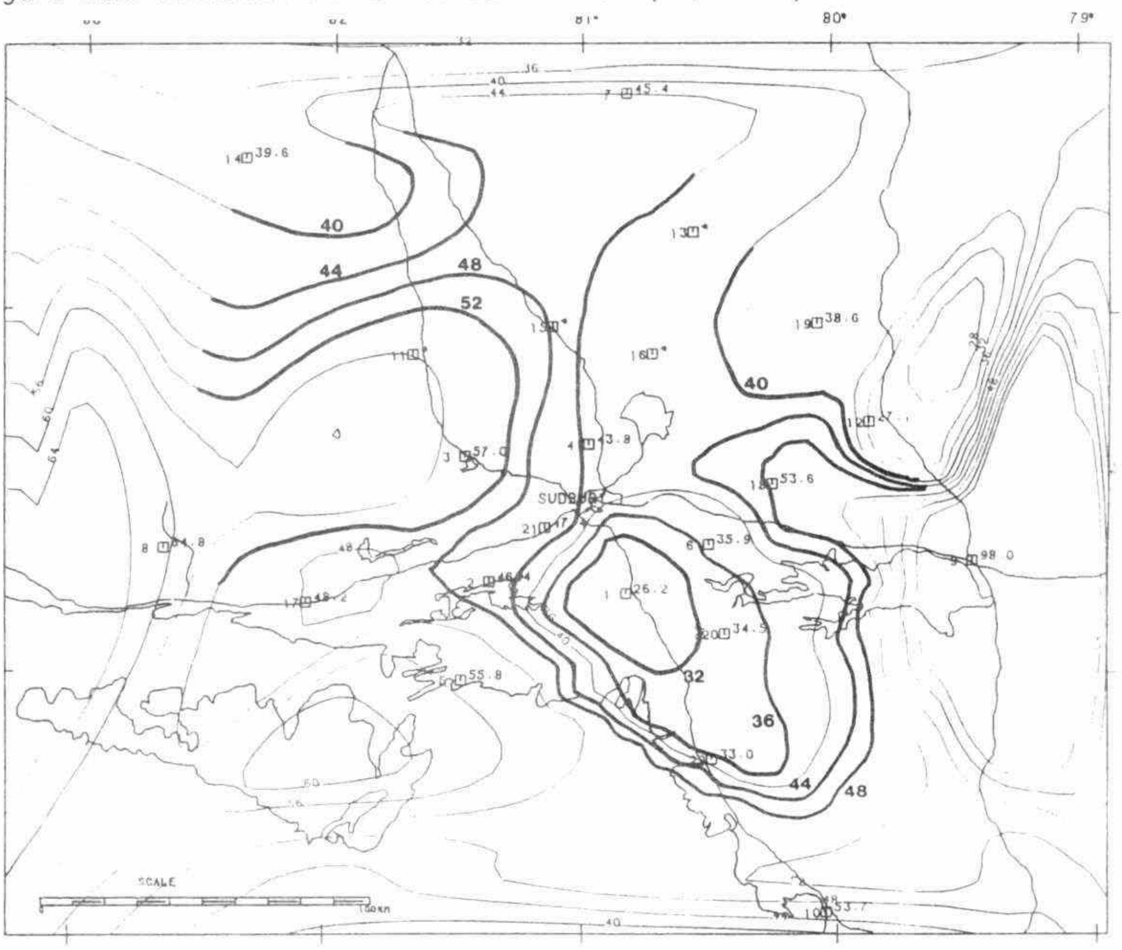


Figure 23b: AVERAGE MONTHLY CONCENTRATION(UG/100 L) OF CR - JUN 79 TO MAY 80

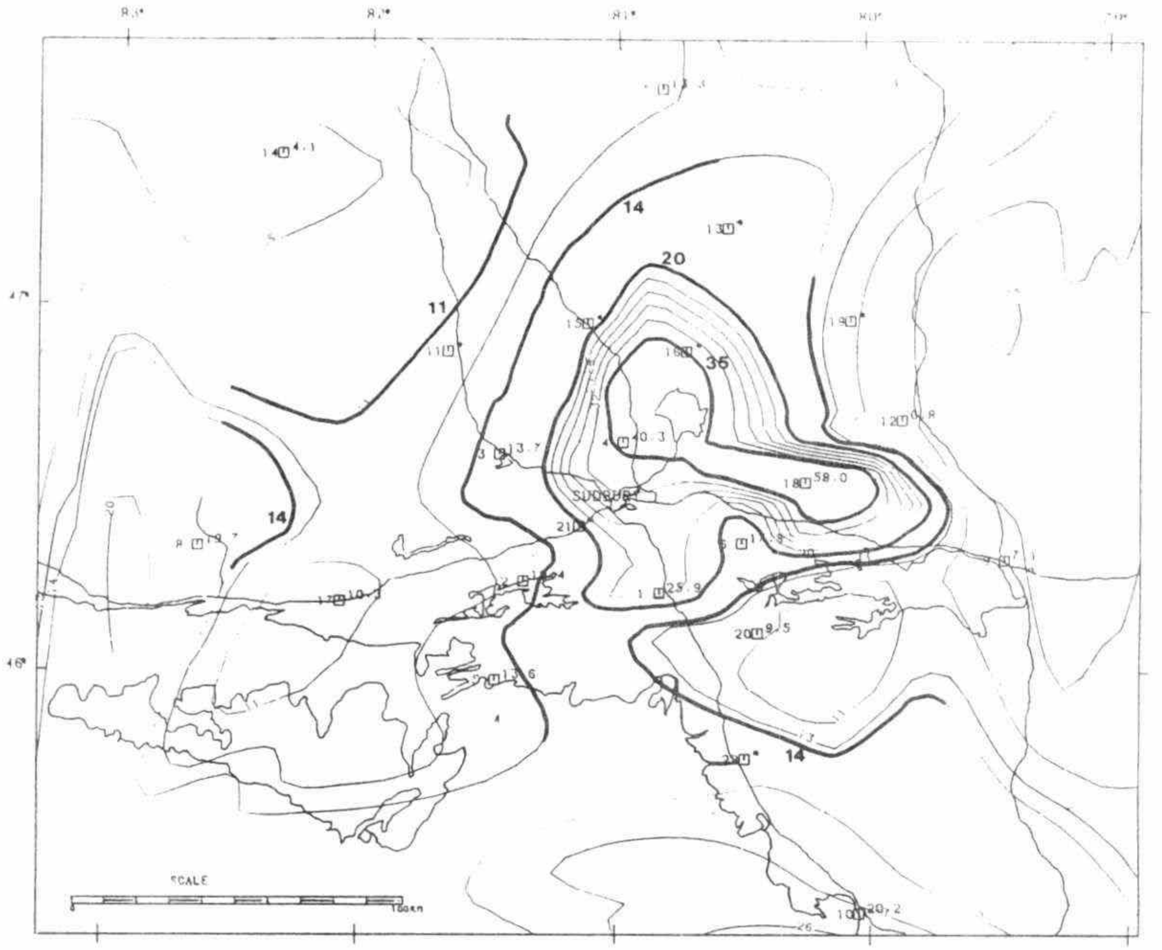


Figure 24a: AVERAGE MONTHLY CONCENTRATION(UG/10 L) OF CD - JUN 78 TO MAY 79

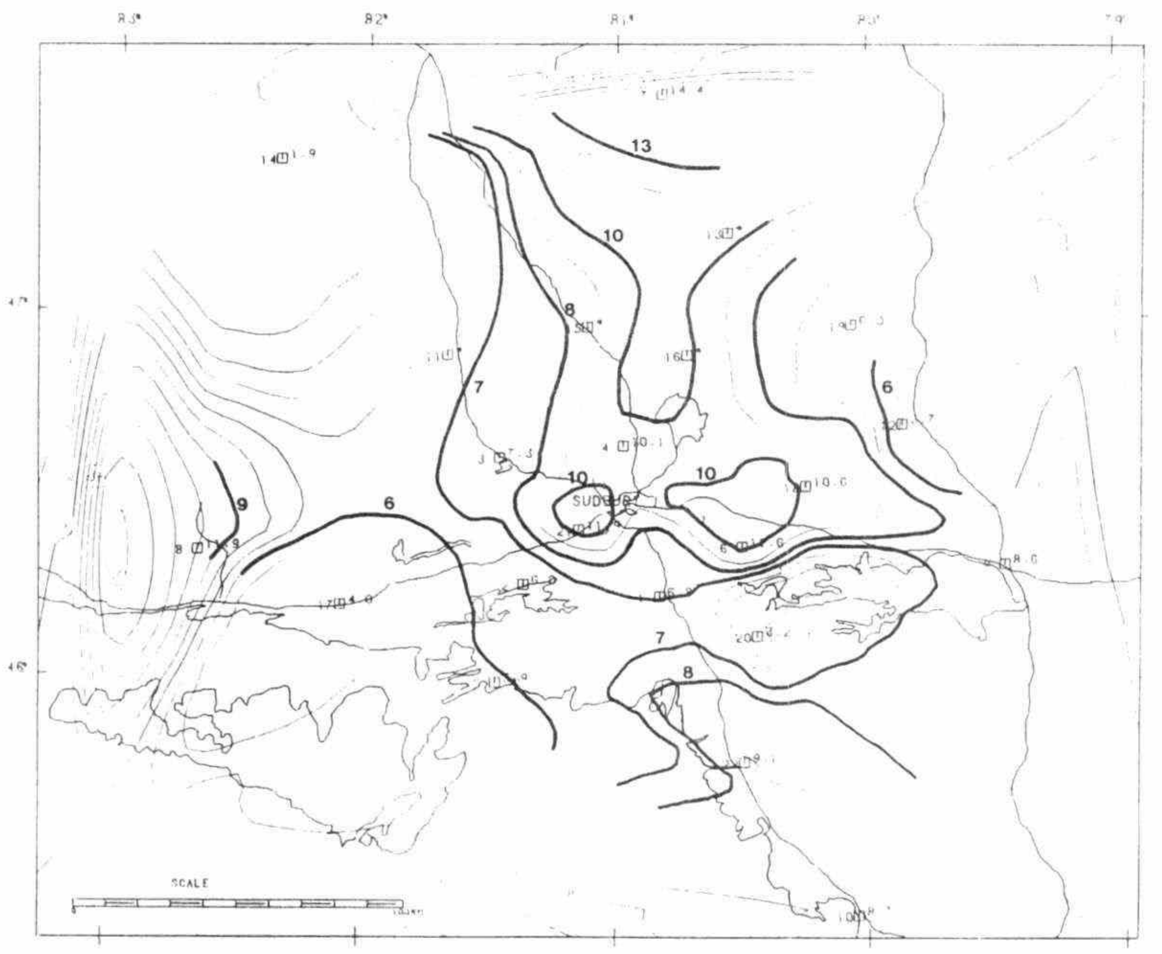


Figure 24b: AVERAGE MONTHLY CONCENTRATION(UG/10 L) OF CD - JUN 79 TO MAY 8J

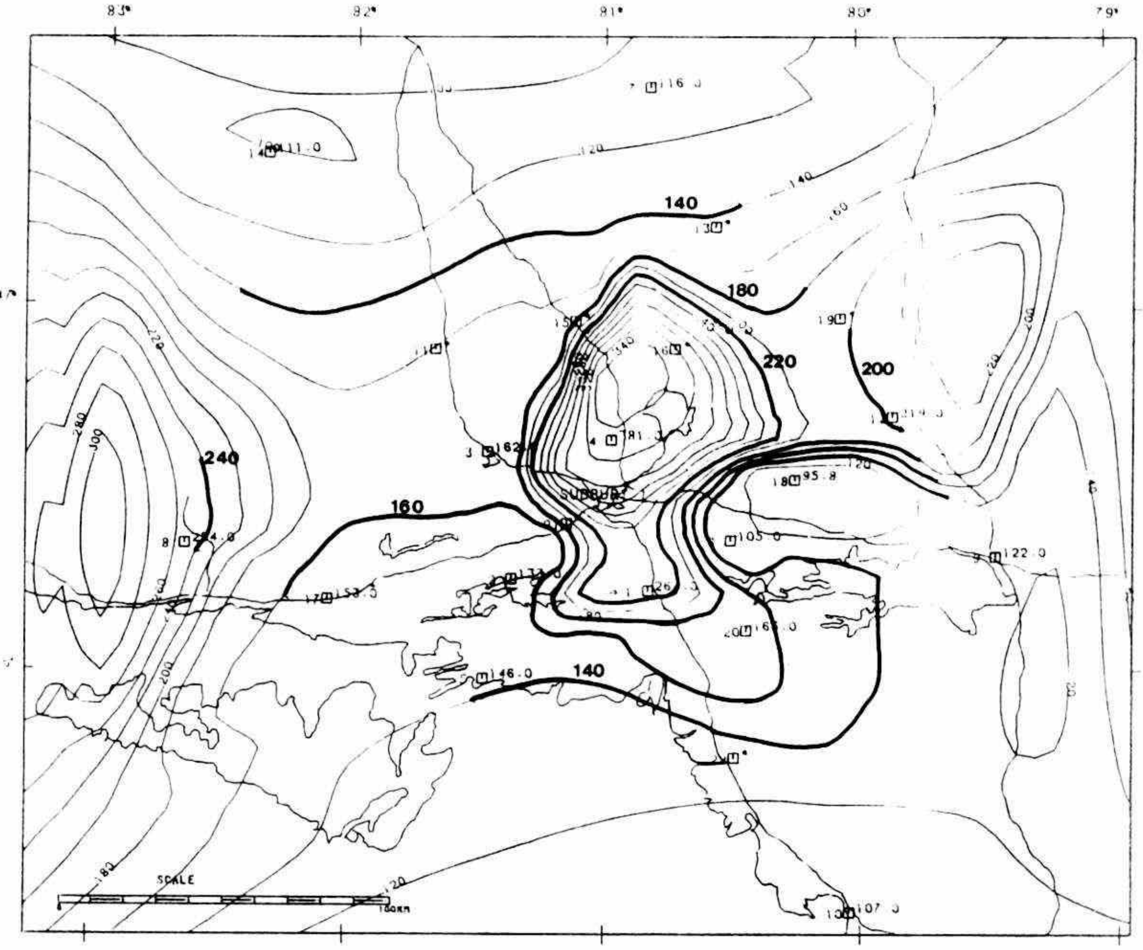


Figure 25a: AVERAGE MONTHLY CONCENTRATION(UG/L) OF NA - JUN 78 TO MAY 79

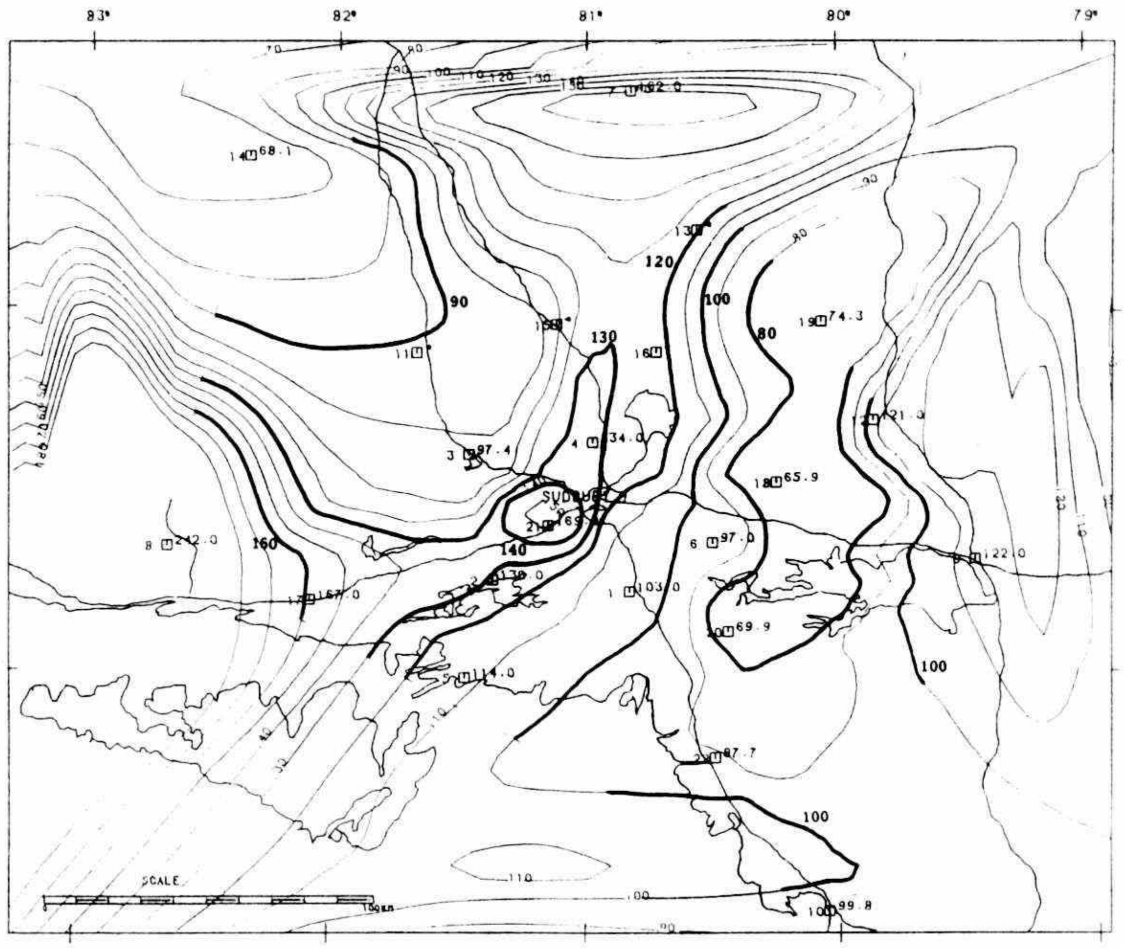


Figure 25b: AVERAGE MONTHLY CONCENTRATION(UG/L) OF NA - JUN 79 TO MAY 80

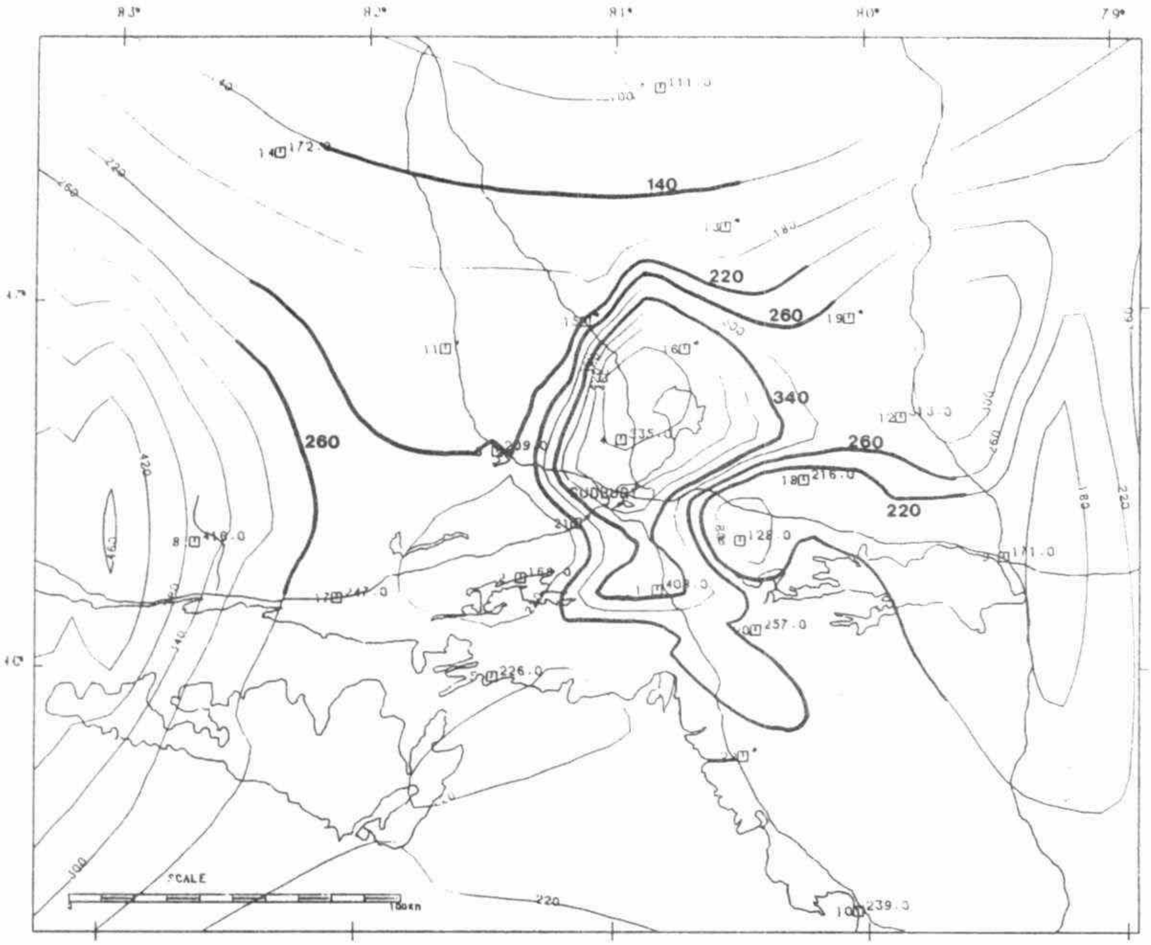


Figure 26a: AVERAGE MONTHLY CONCENTRATION(UG/L) OF CL - JUN 78 TO MAY 79

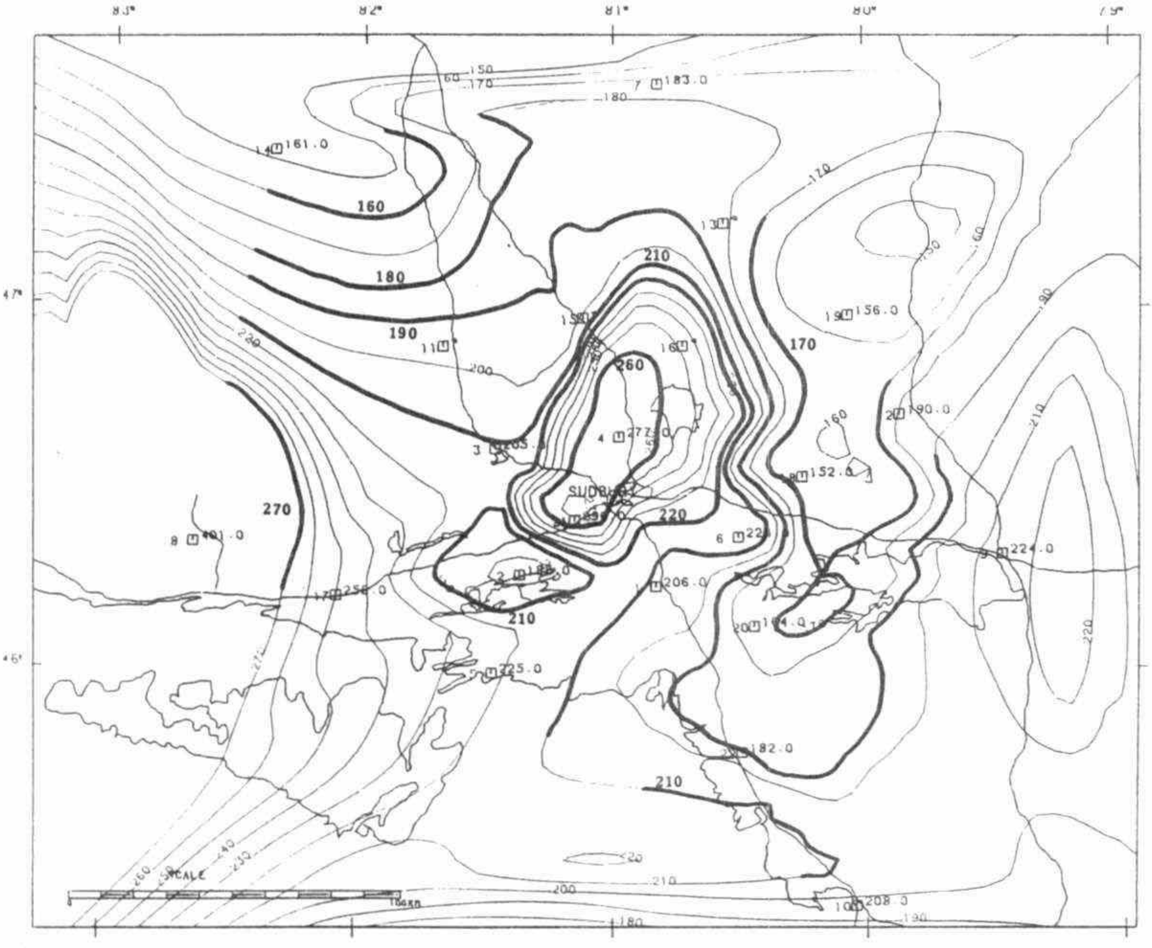


Figure 26b: AVERAGE MONTHLY CONCENTRATION (UG/L) OF CL - JUN 79 TO MAY 80

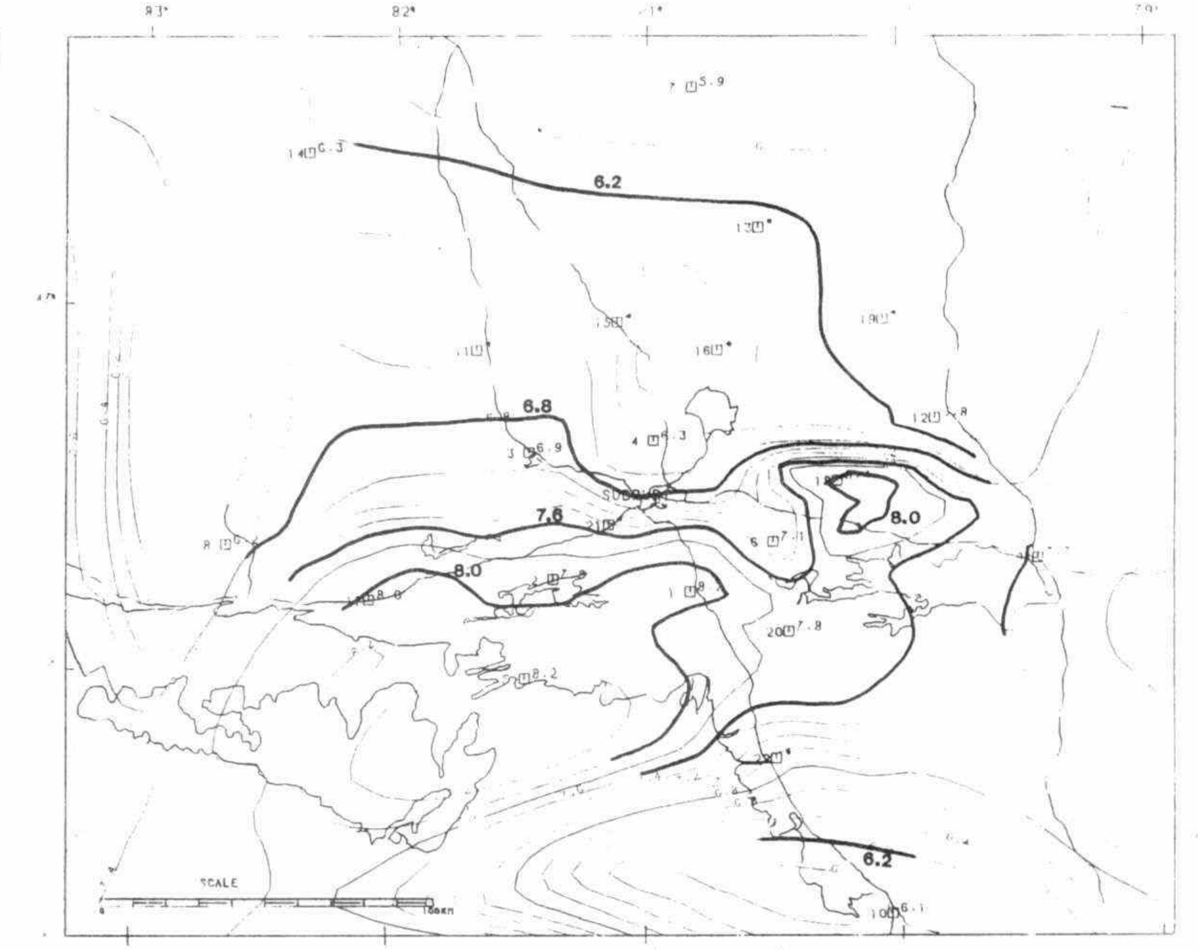


Figure 27a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF H_f - JUN 78 TO MAY 79

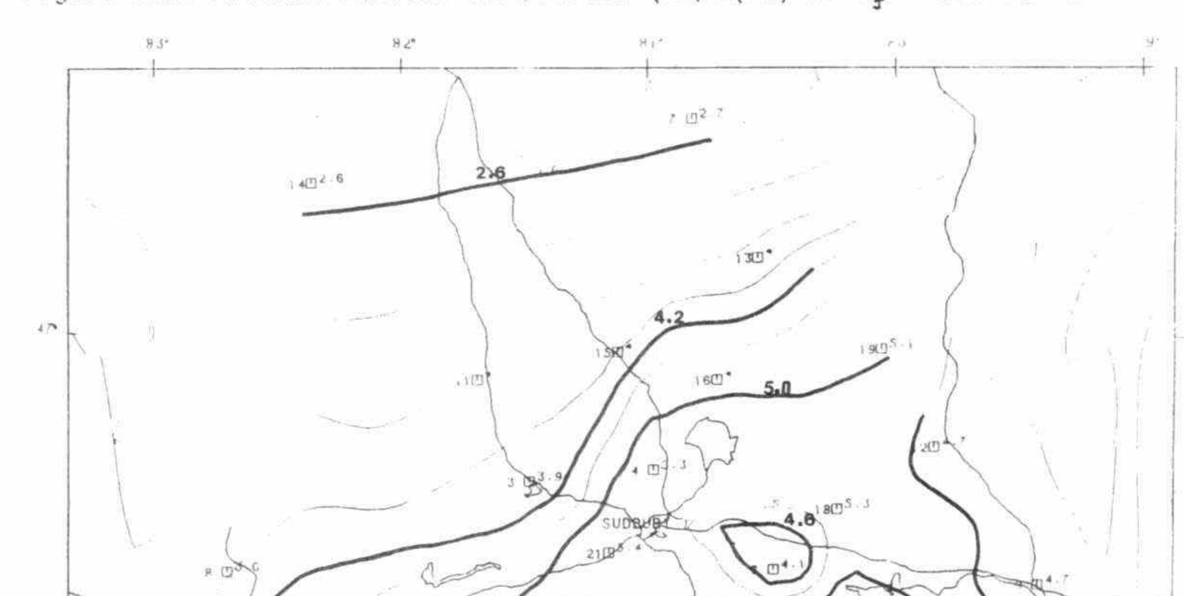


Figure 27b: AVERAGE MONTHLY DEPOSITION(MG/SQ.M) OF H_f - JUN 79 TO MAY 80

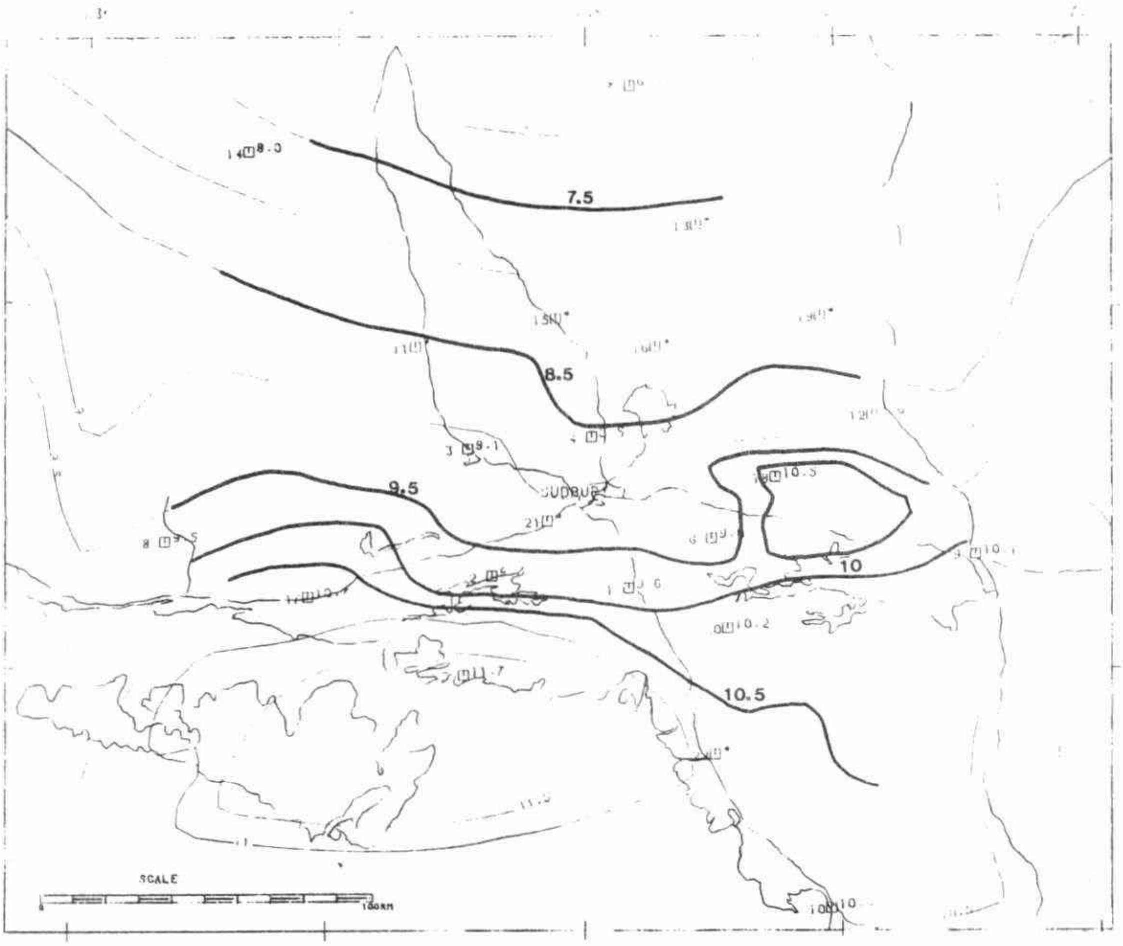


Figure 28a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF H± -JUN 78 to MAY 79

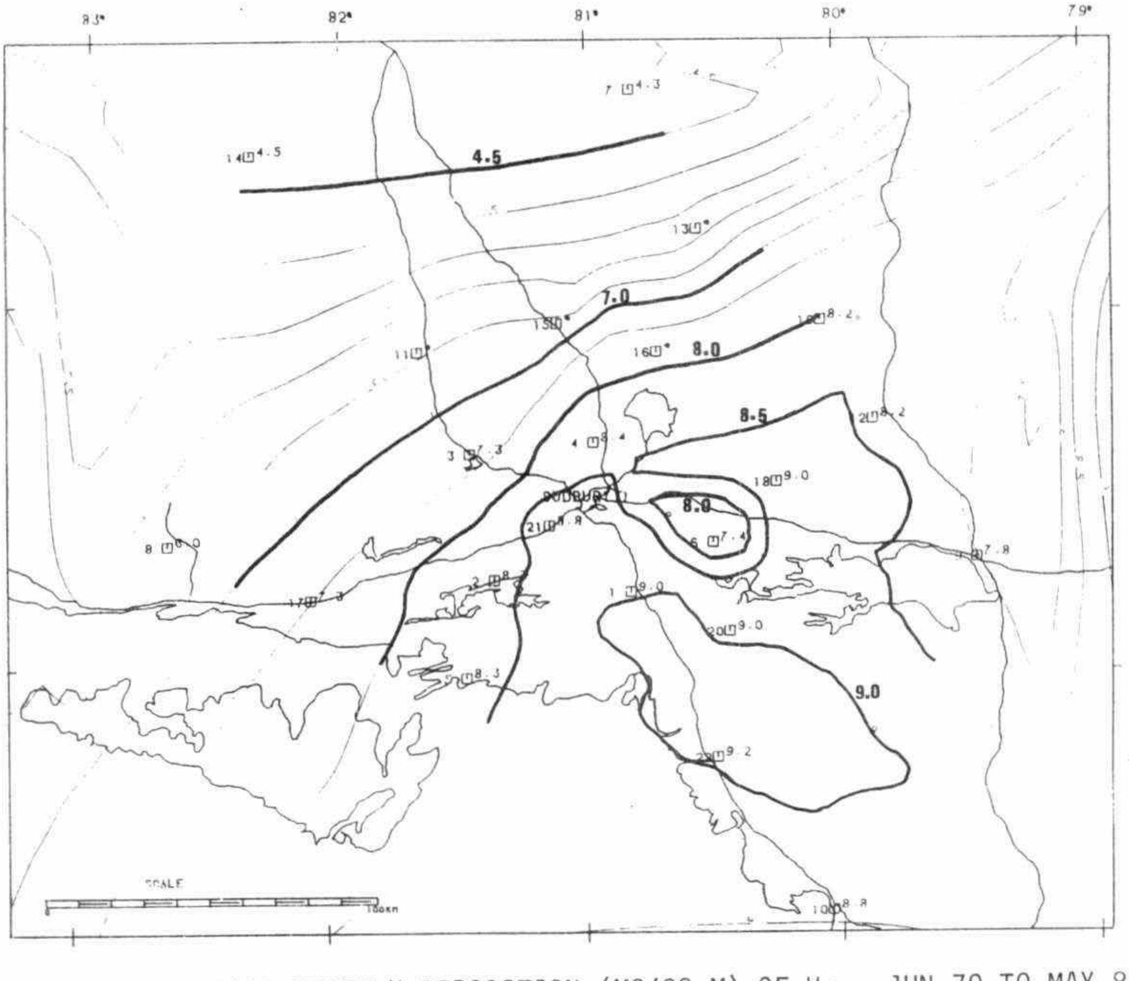


Figure 28b: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF H± - JUN 79 TO MAY 80

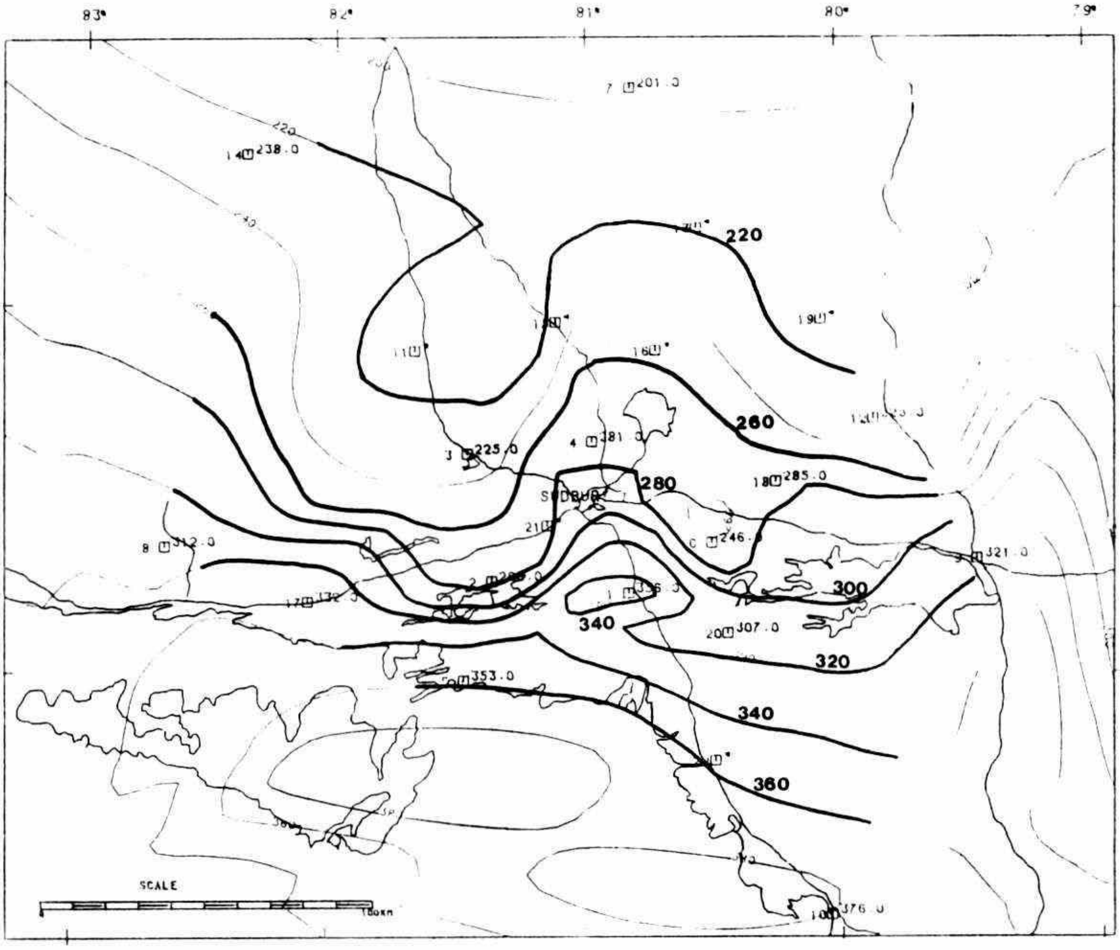


Figure 29a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF SO4 - JUN 78 TO MAY 79

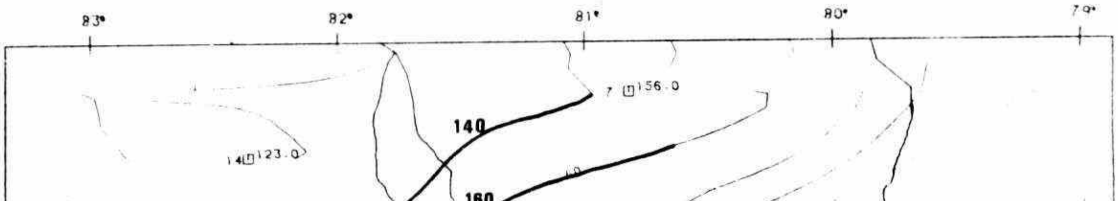


Figure 29b: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF SO4 - JUN 79 TO MAY 80

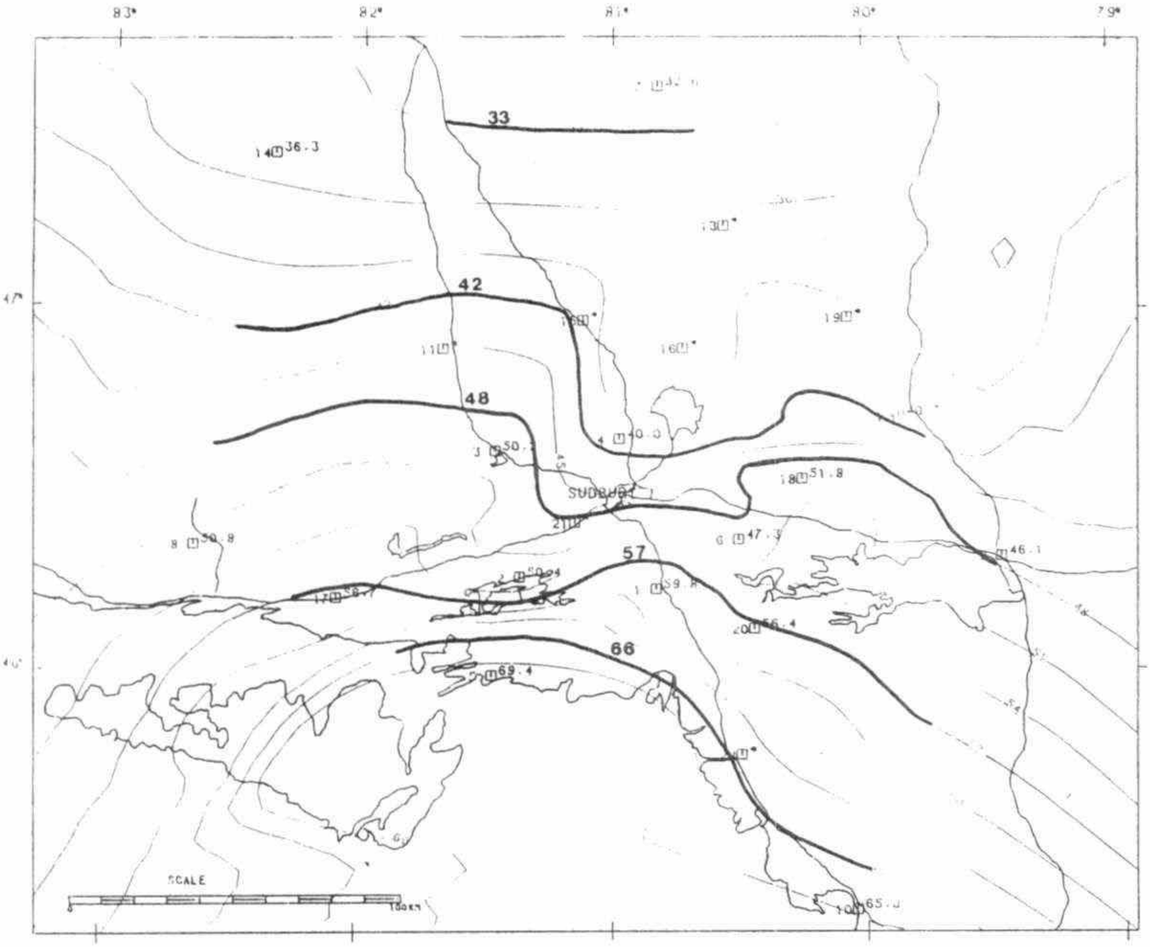


Figure 30a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF N-NO3 - JUN 78 TO MAY 79

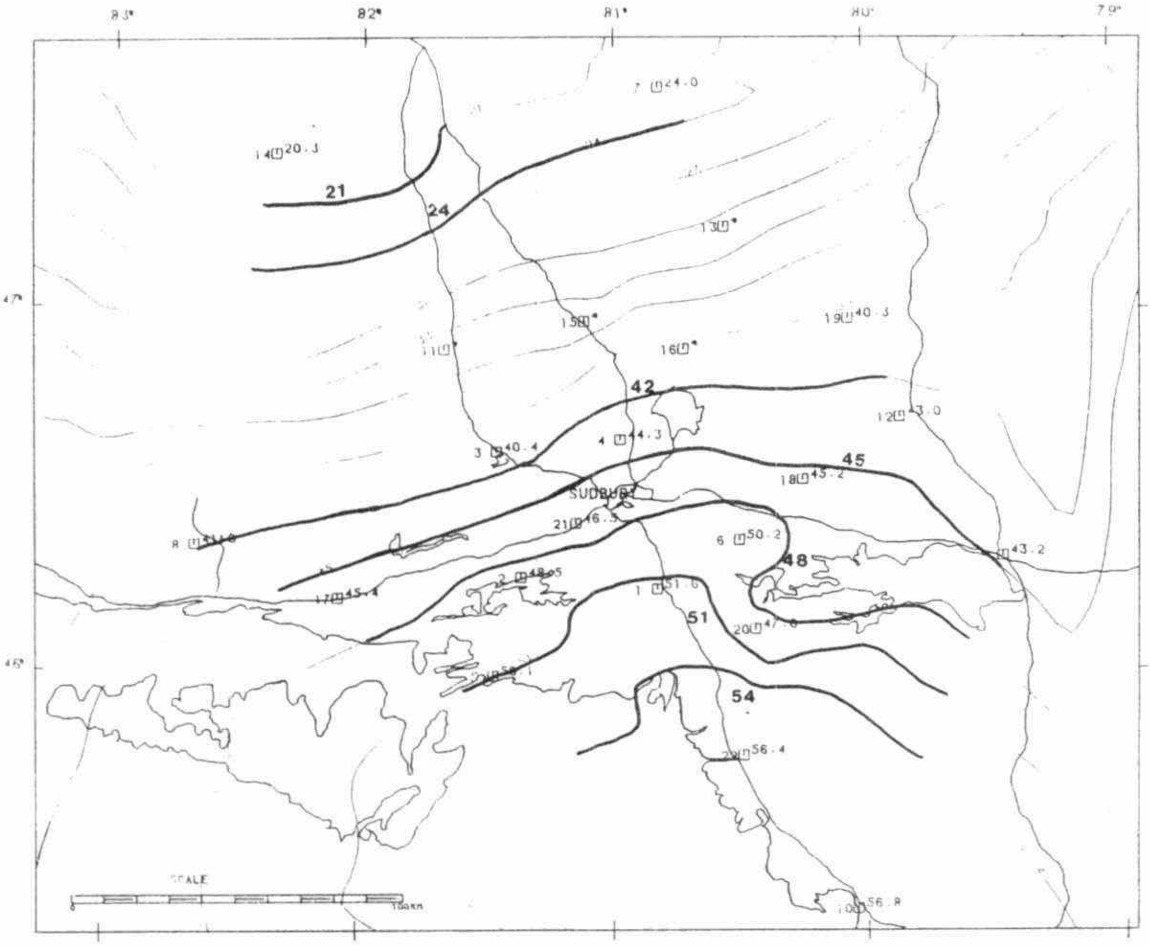


Figure 30b: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF N-NO3 - JUN 79 TO MAY 80

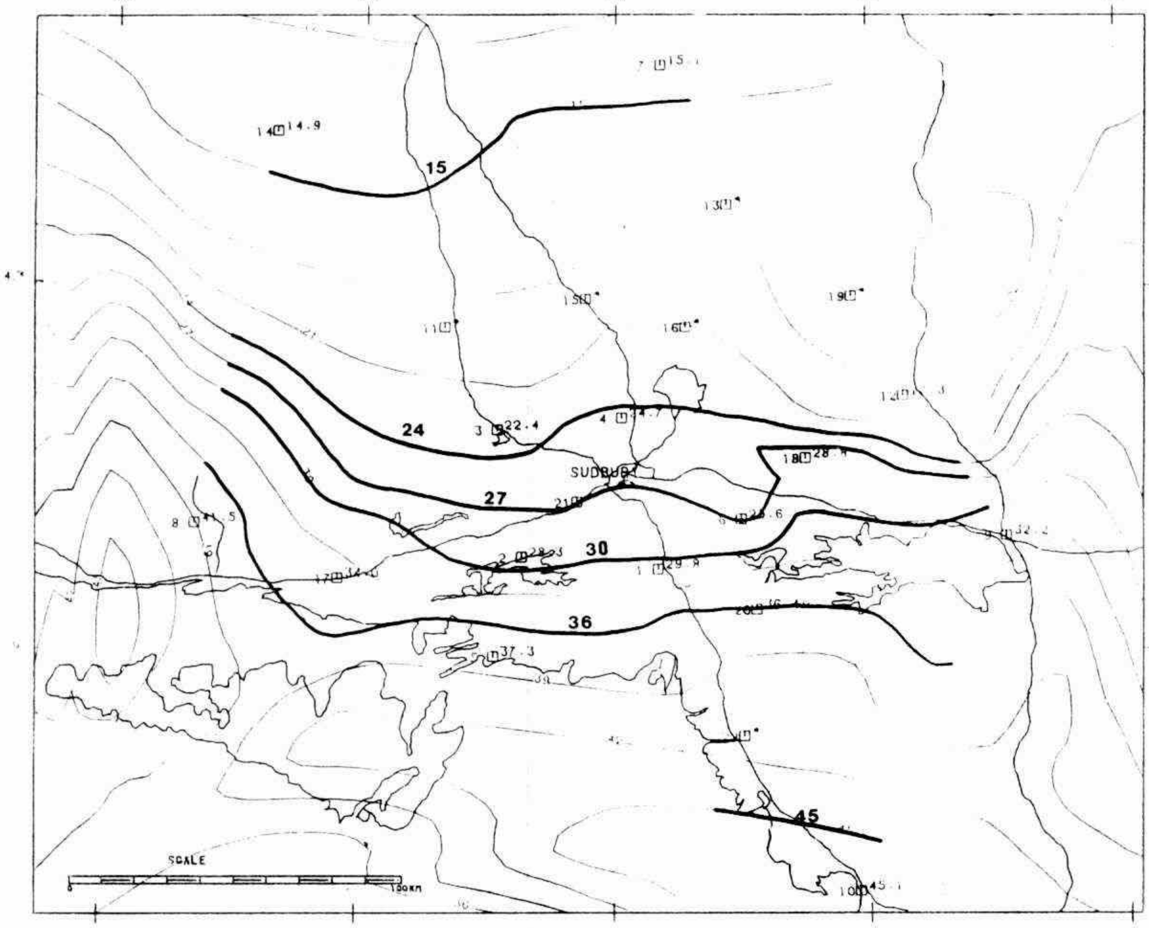


Figure 31a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF N-NH4 - JUN 78 TO MAY 79

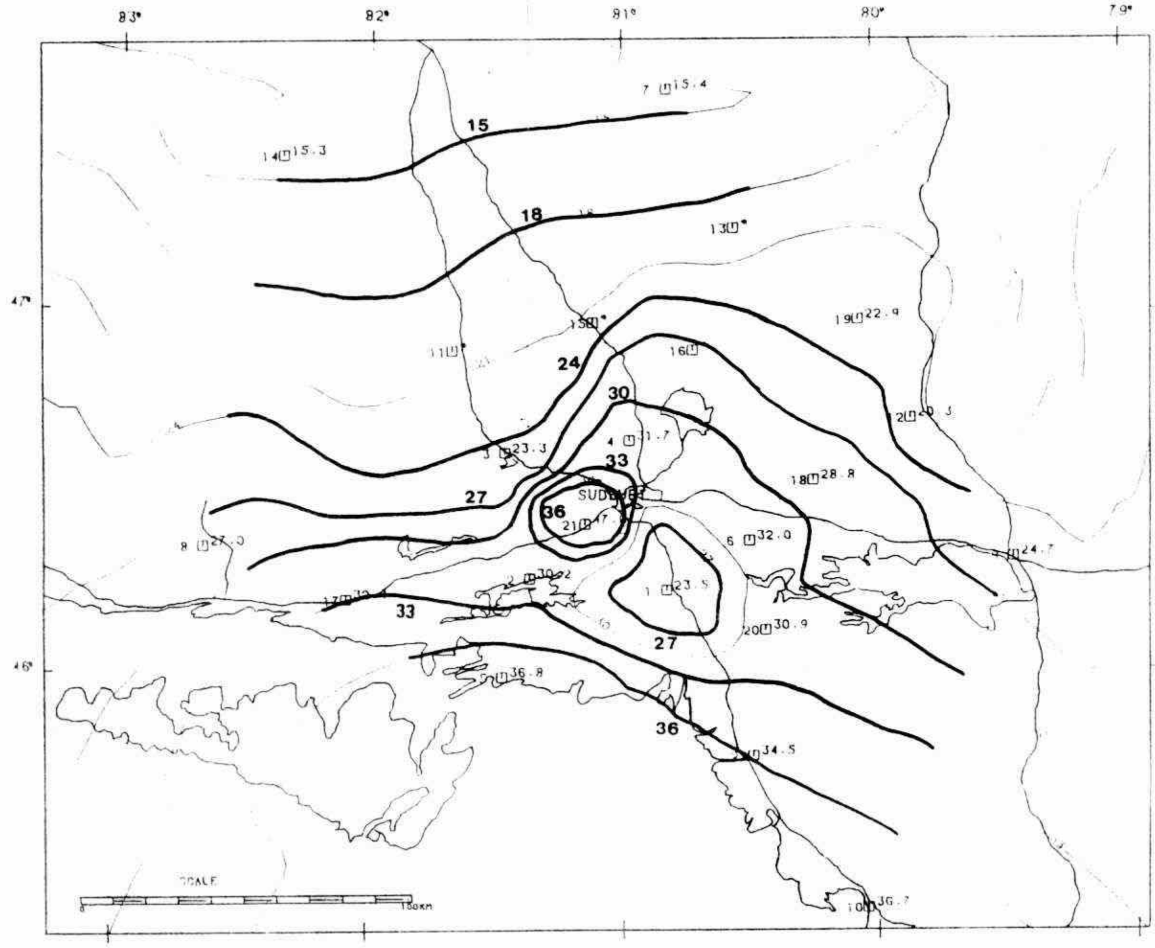


Figure 31b: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF N-NH4 - JUN 79 TO MAY 80

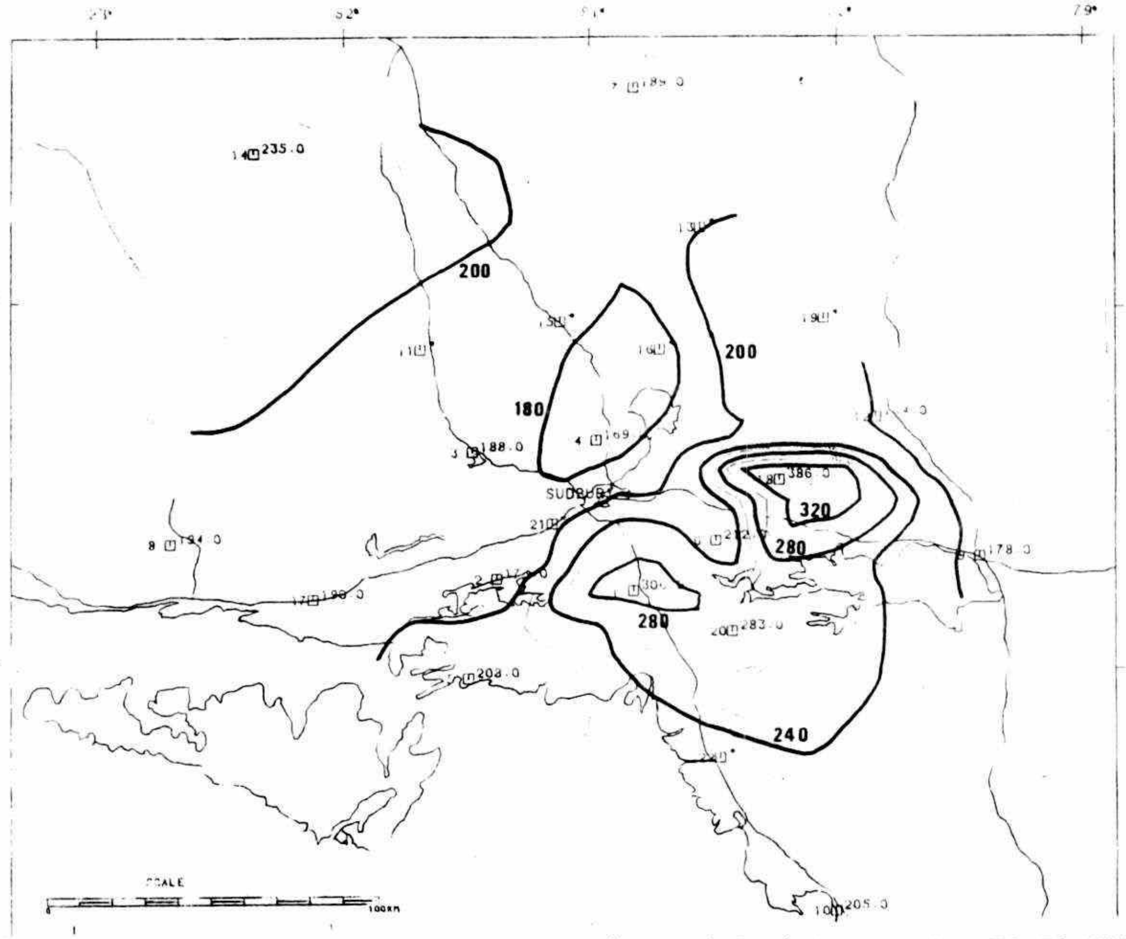


Figure 32a: AVERAGE MONTHLY DEPOSITION (10 UG/SQ.M) OF F - JUN 78 TO MAY 79

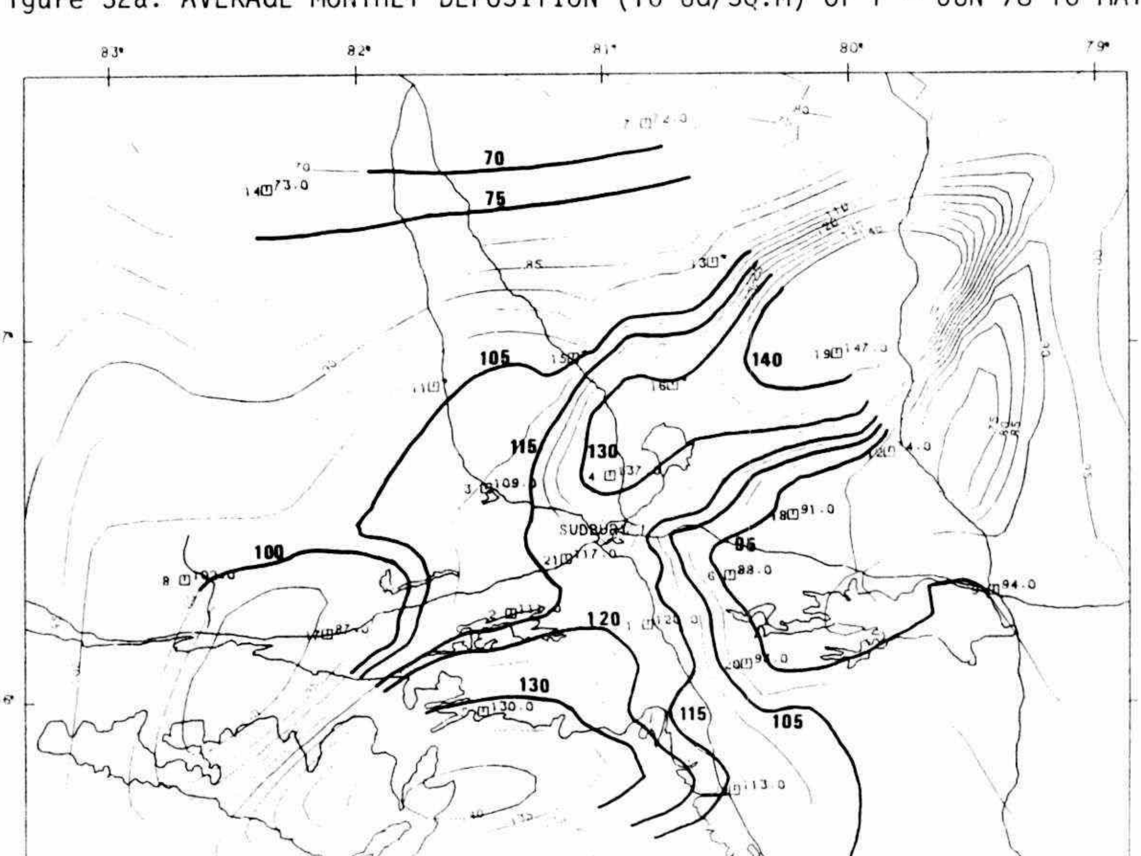


Figure 32b: AVERAGE MONTHLY DEPOSITION (10 UG/SQ.M) OF F - JUN 79 TO MAY 80

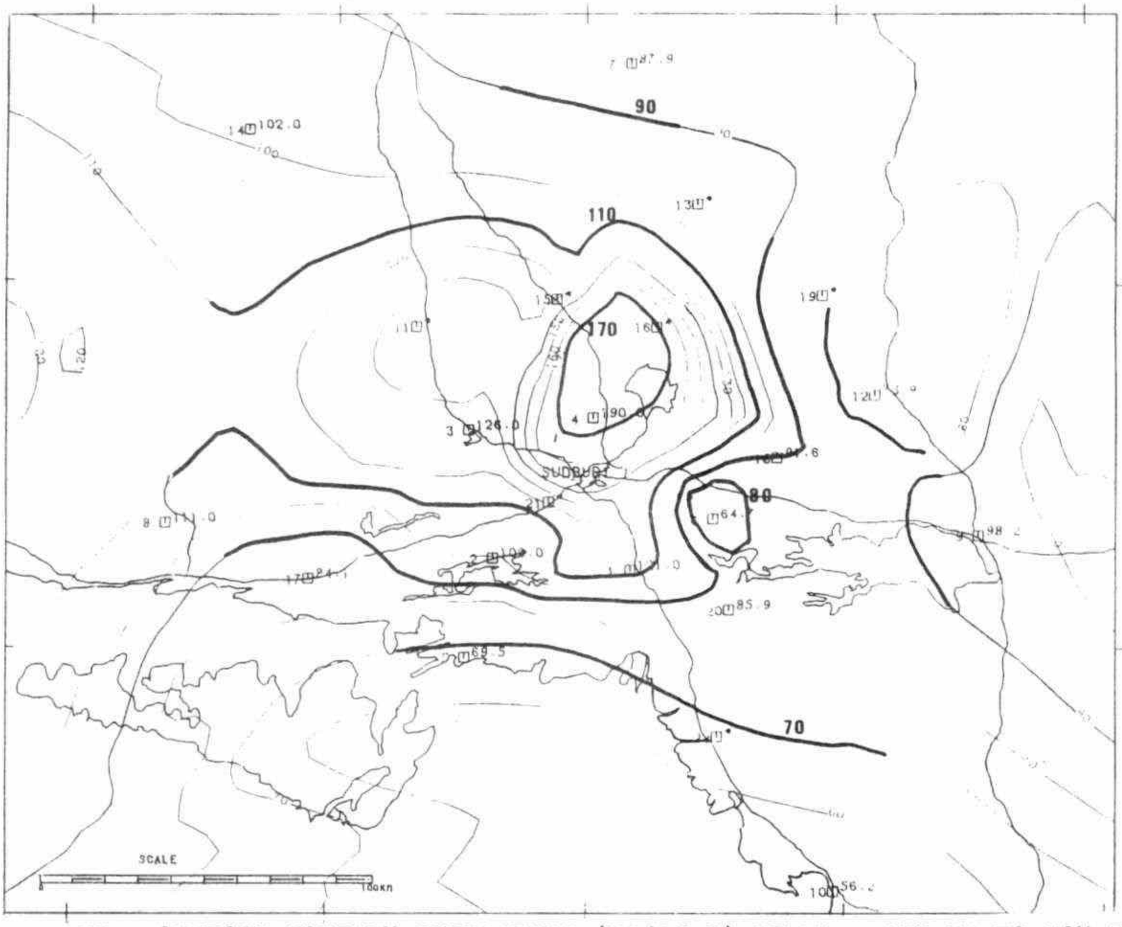


Figure 33a: AVERAGE MONTHLY DEPOSITION (UG/SQ.M) OF NI - JUN 78 TO MAY 79

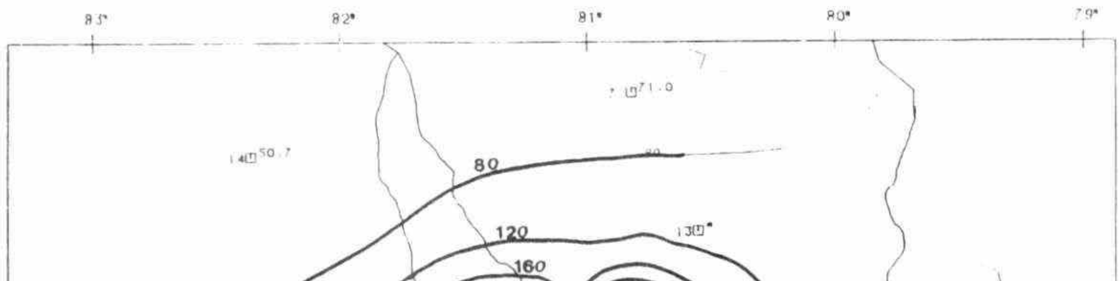


Figure 33b: AVERAGE MONTHLY DEPOSITION (UG/SQ.M) OF NI - JUN 79 TO MAY 80

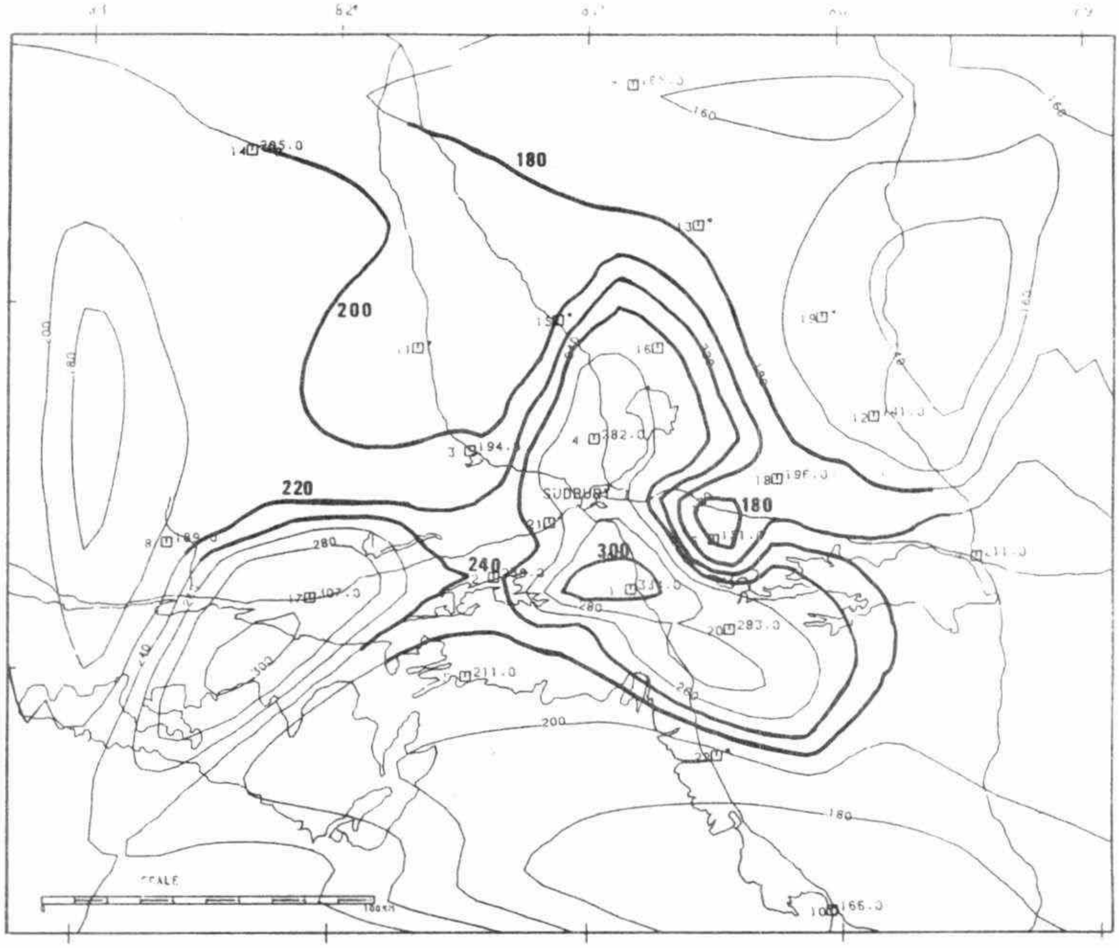


Figure 34a: AVERAGE MONTHLY DEPOSITION (UG/SQ.M) OF CU - JUN 78 TO MAY 79

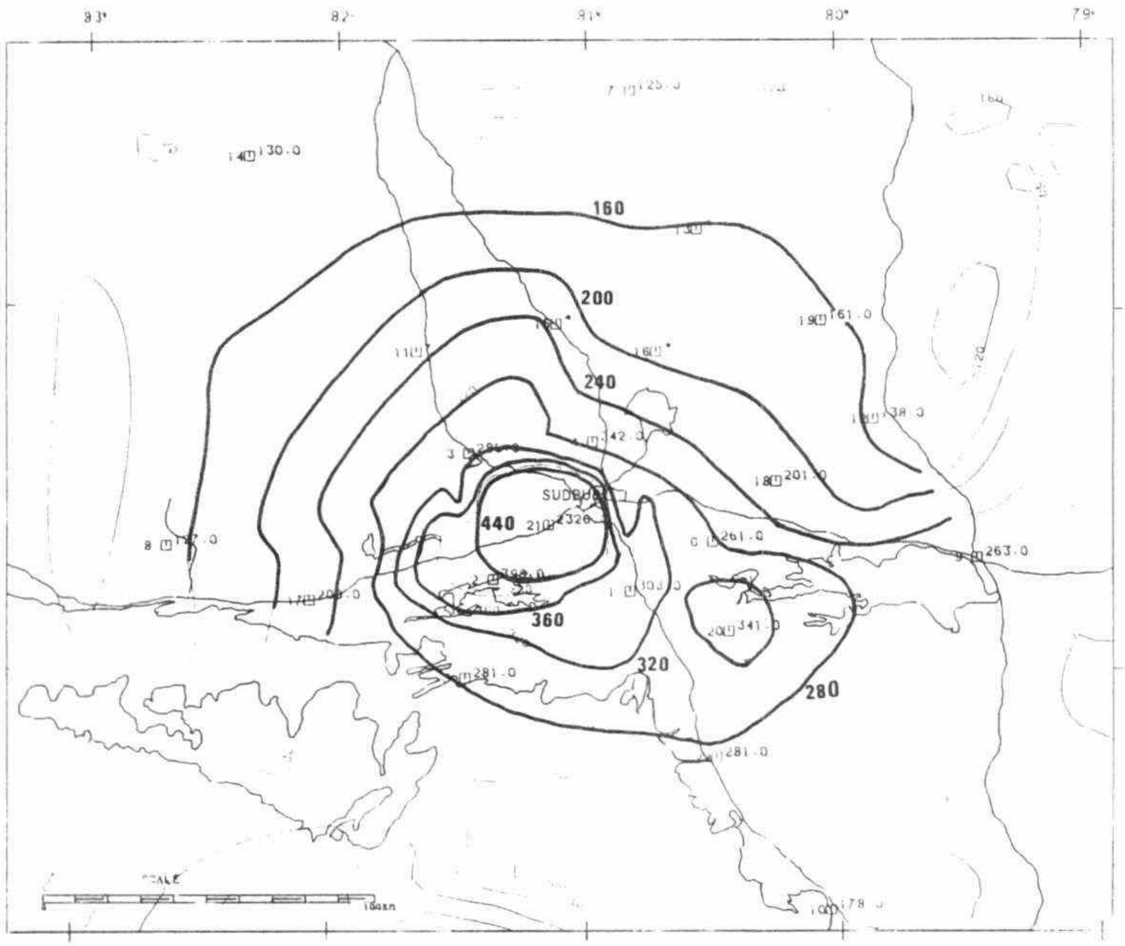


Figure 34b: AVERAGE MONTHLY DEPOSITION (UG/SQ.M) OF CU - JUN 79 TO MAY 80

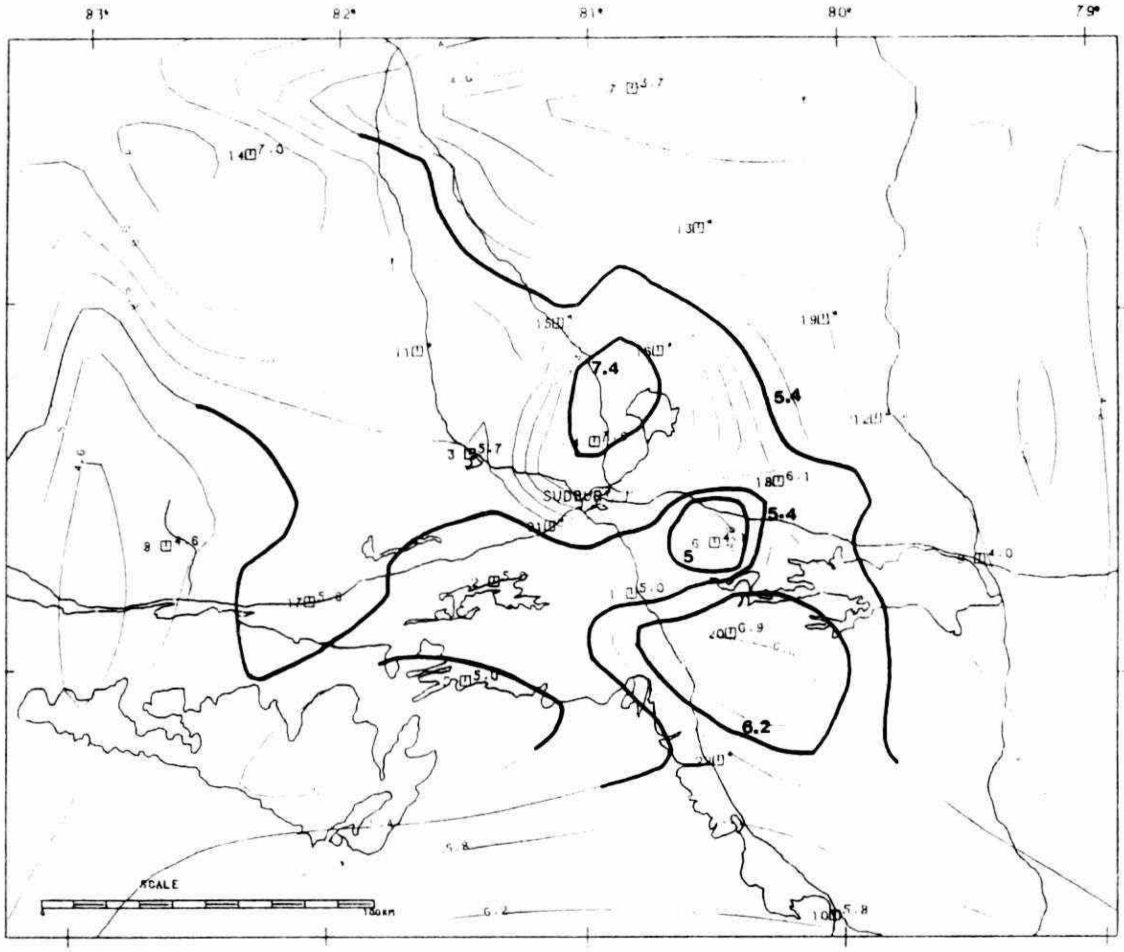


Figure 35a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF FE - JUN 78 TO MAY 79

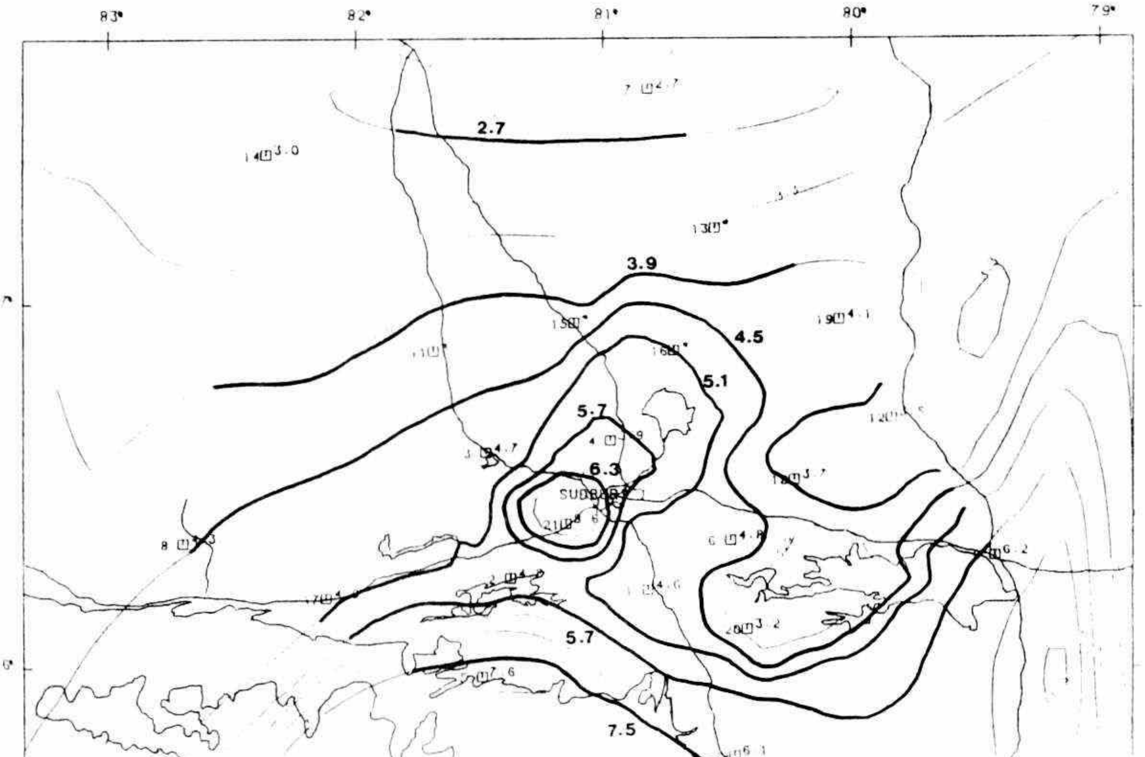


Figure 35b: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF FE - JUN 79 TO MAY 80

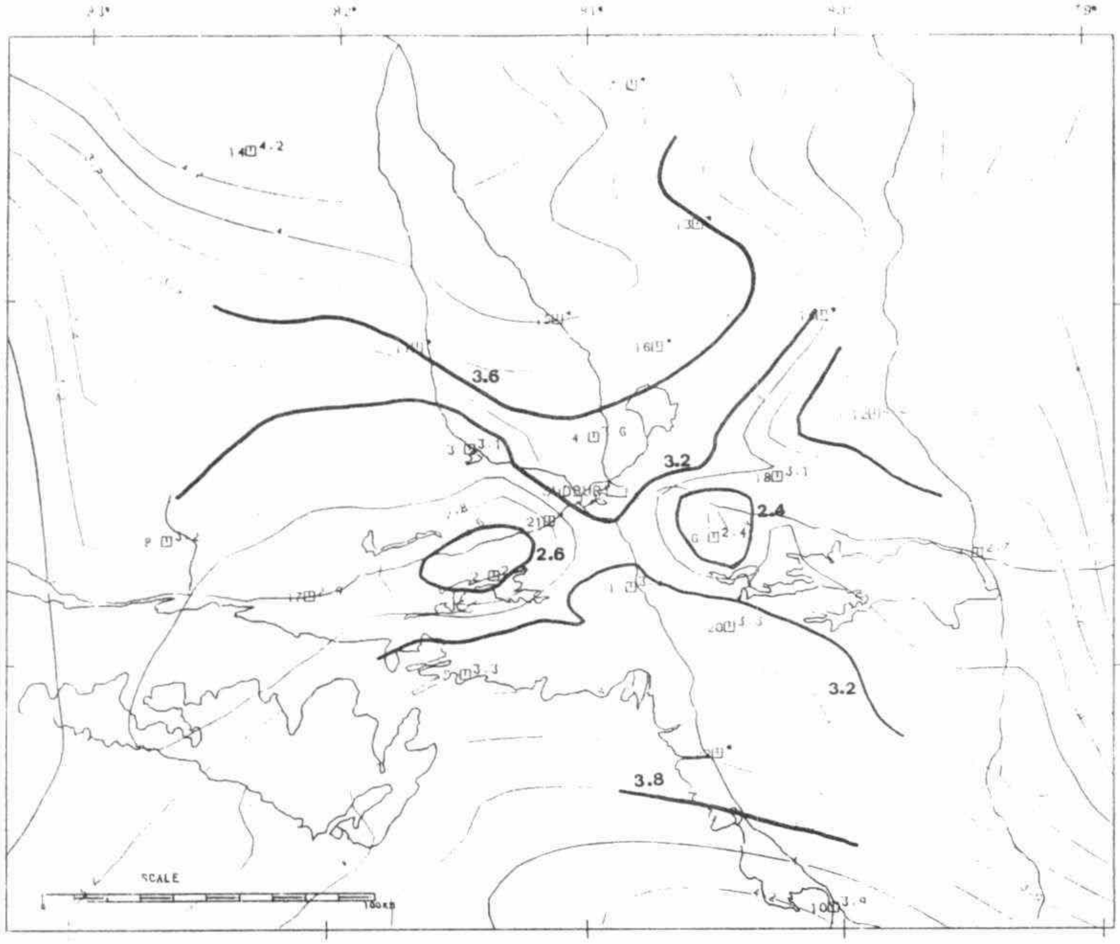


Figure 36a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF AL - JUN 78 TO MAY 79

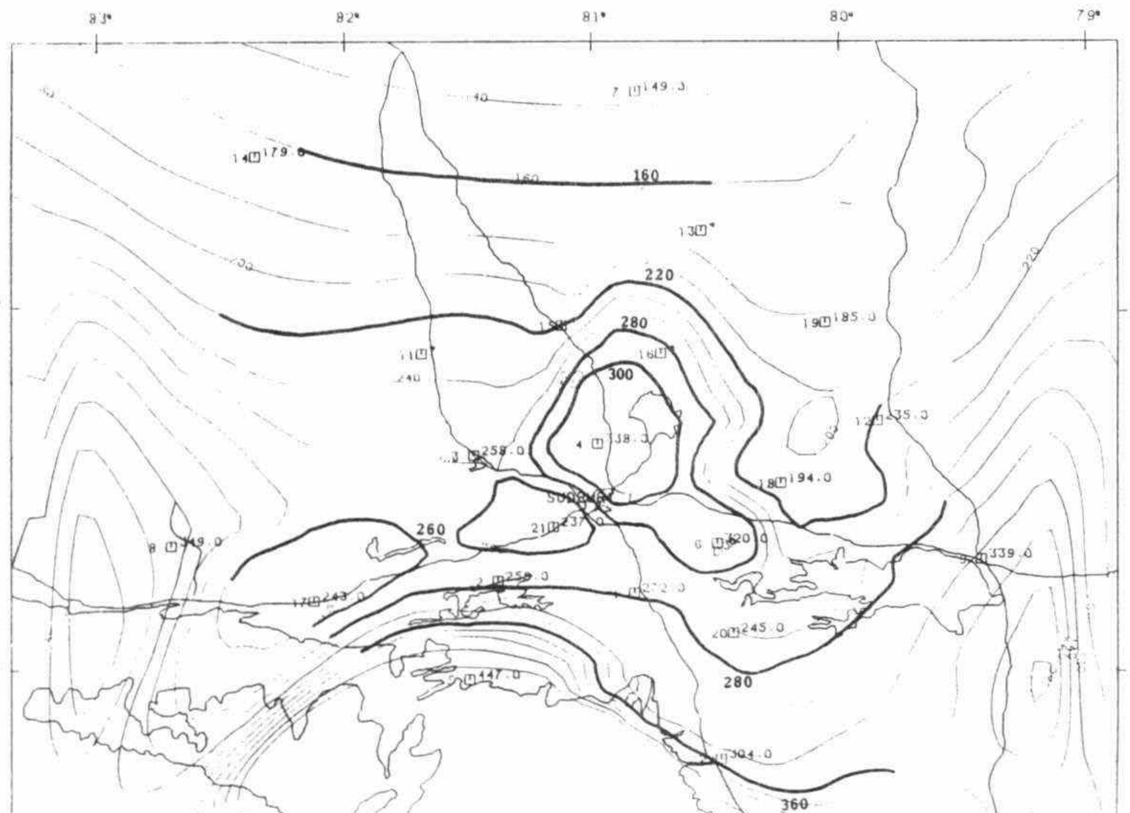


Figure 36b: AVERAGE MONTHLY DEPOSITION (10 UG/SQ.M) OF AL - JUN 79 to MAY 80

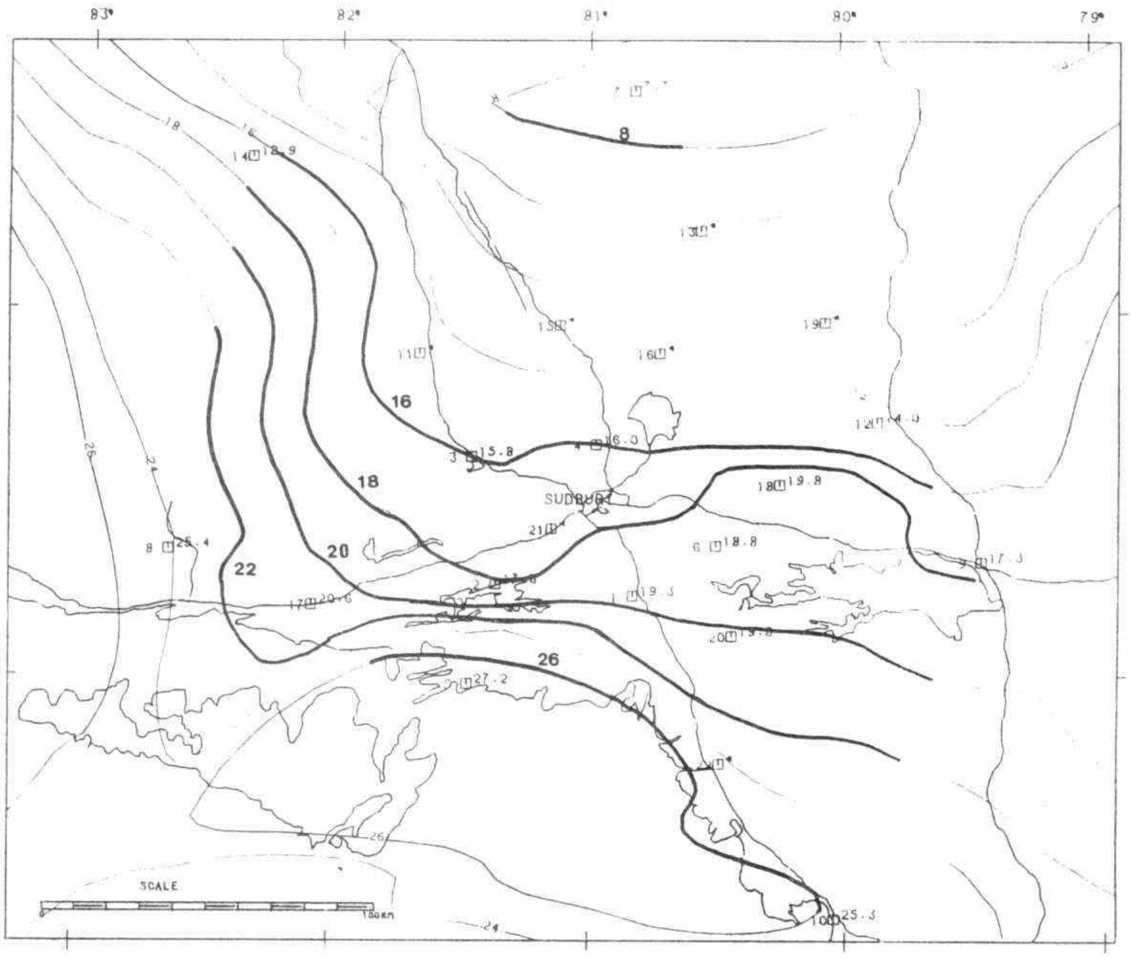


Figure 37a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF CA - JUN 78 TO MAY 79

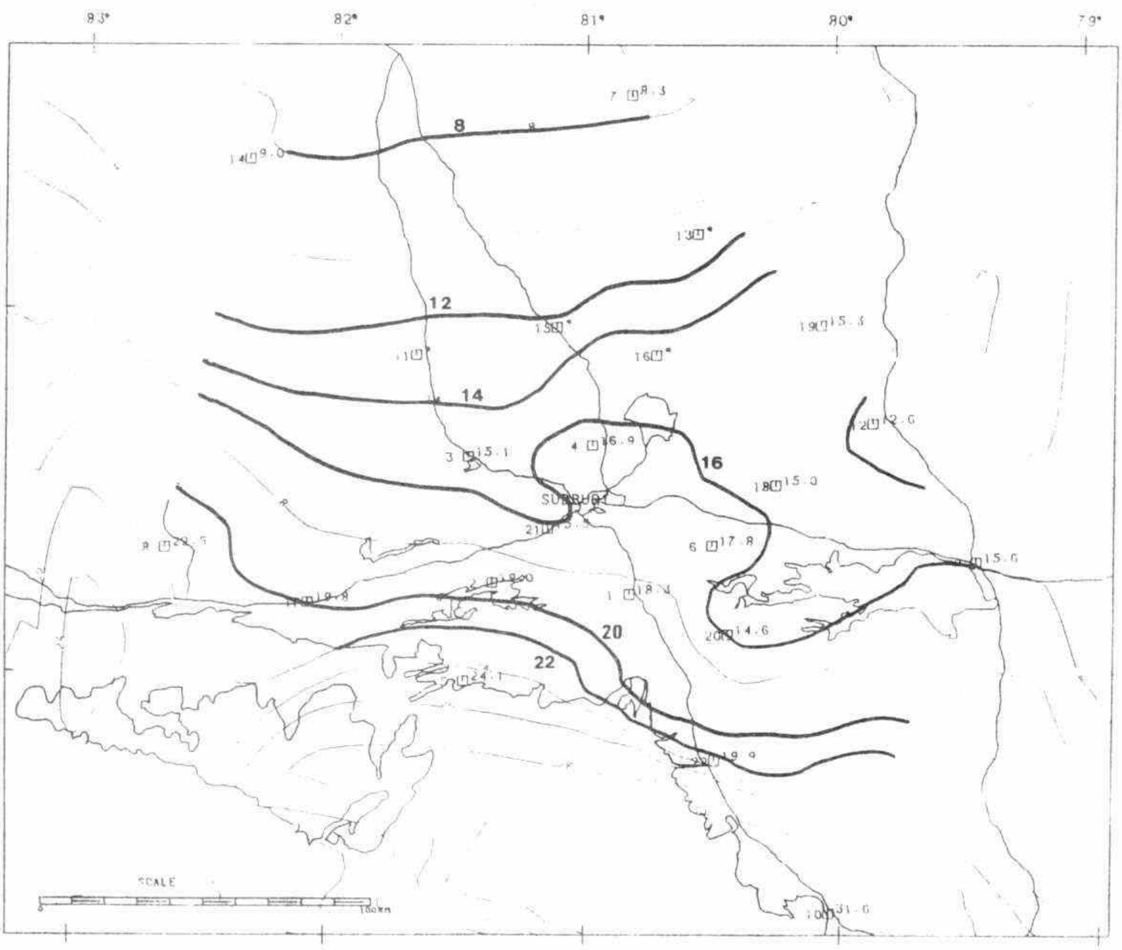


Figure 37b: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF CA - JUN 79 TO MAY 80

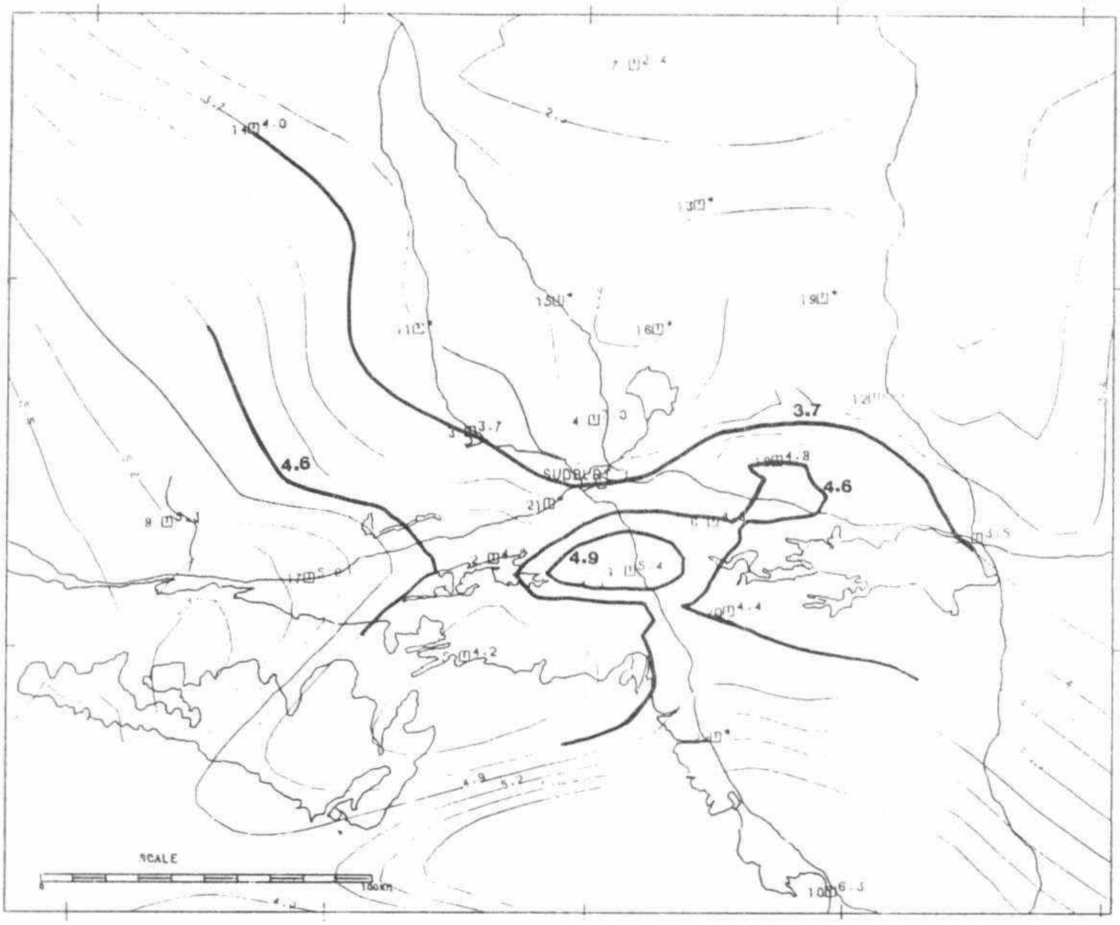


Figure 38a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF MG - JUN 78 TO MAY 79

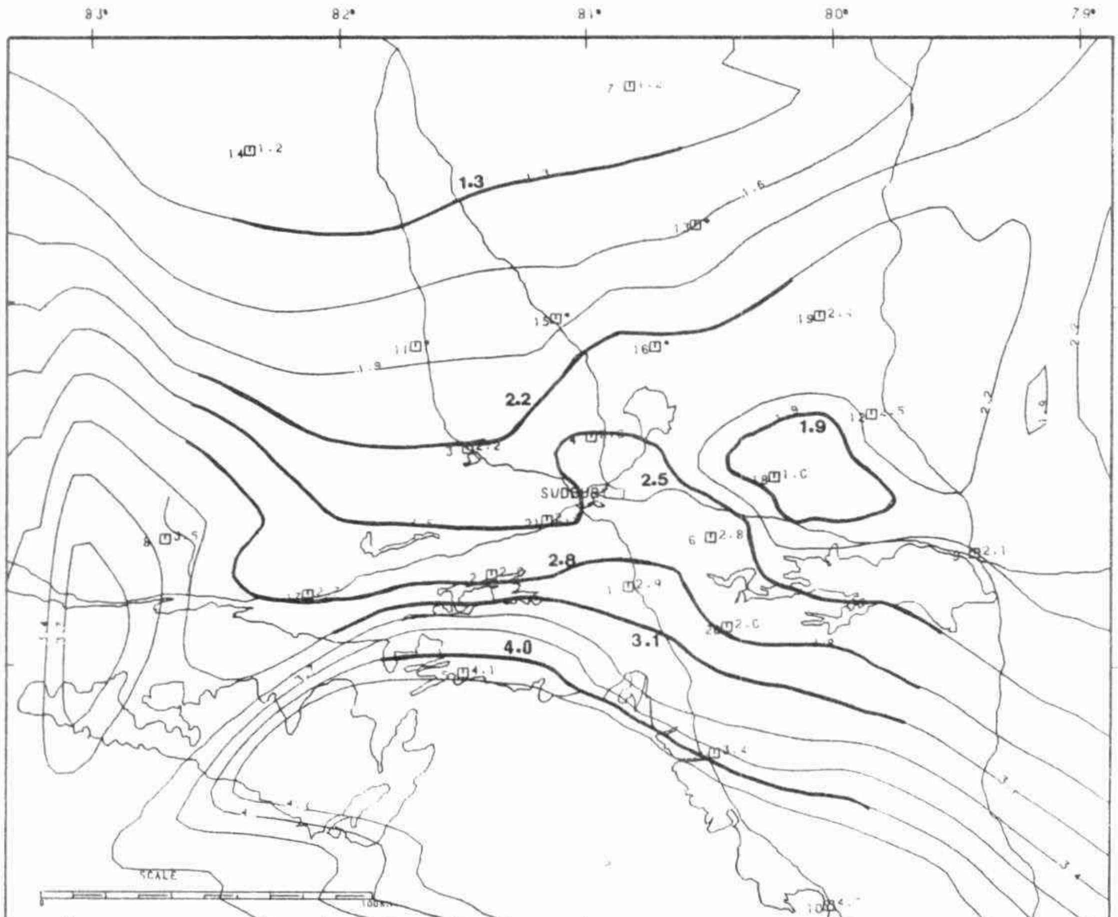


Figure 38b: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF MG - JUN 79 TO MAY 80

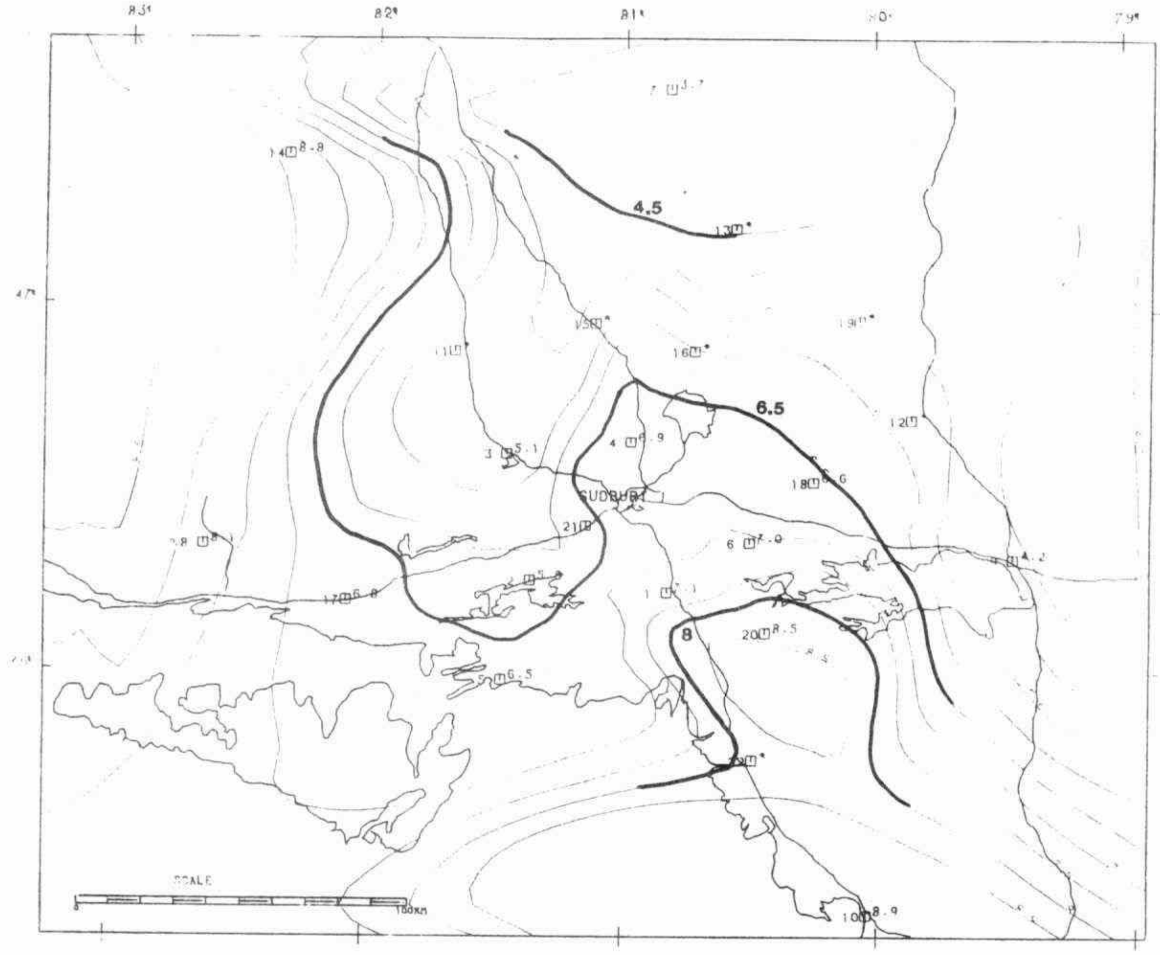


Figure 39a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF K - JUN 78 TO MAY 79

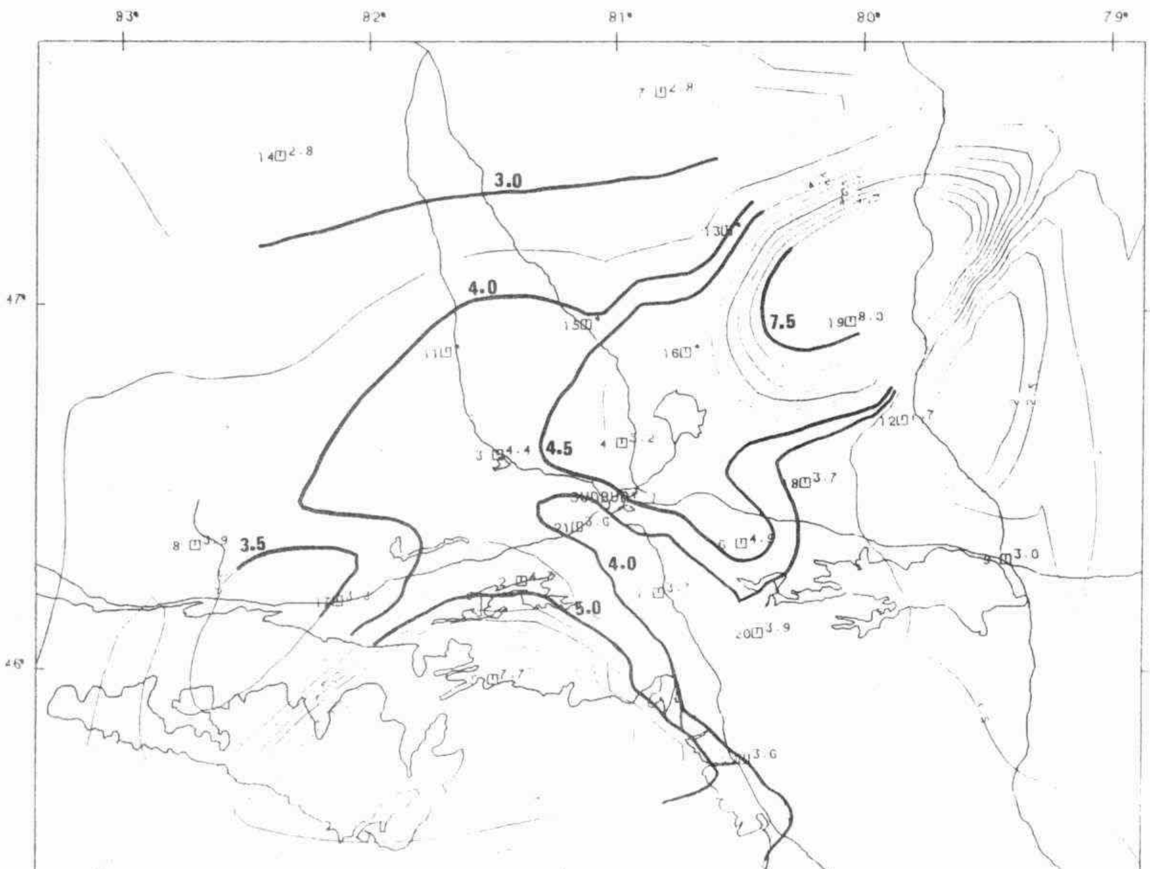


Figure 39b: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF K - JUN 79 TO MAY 80

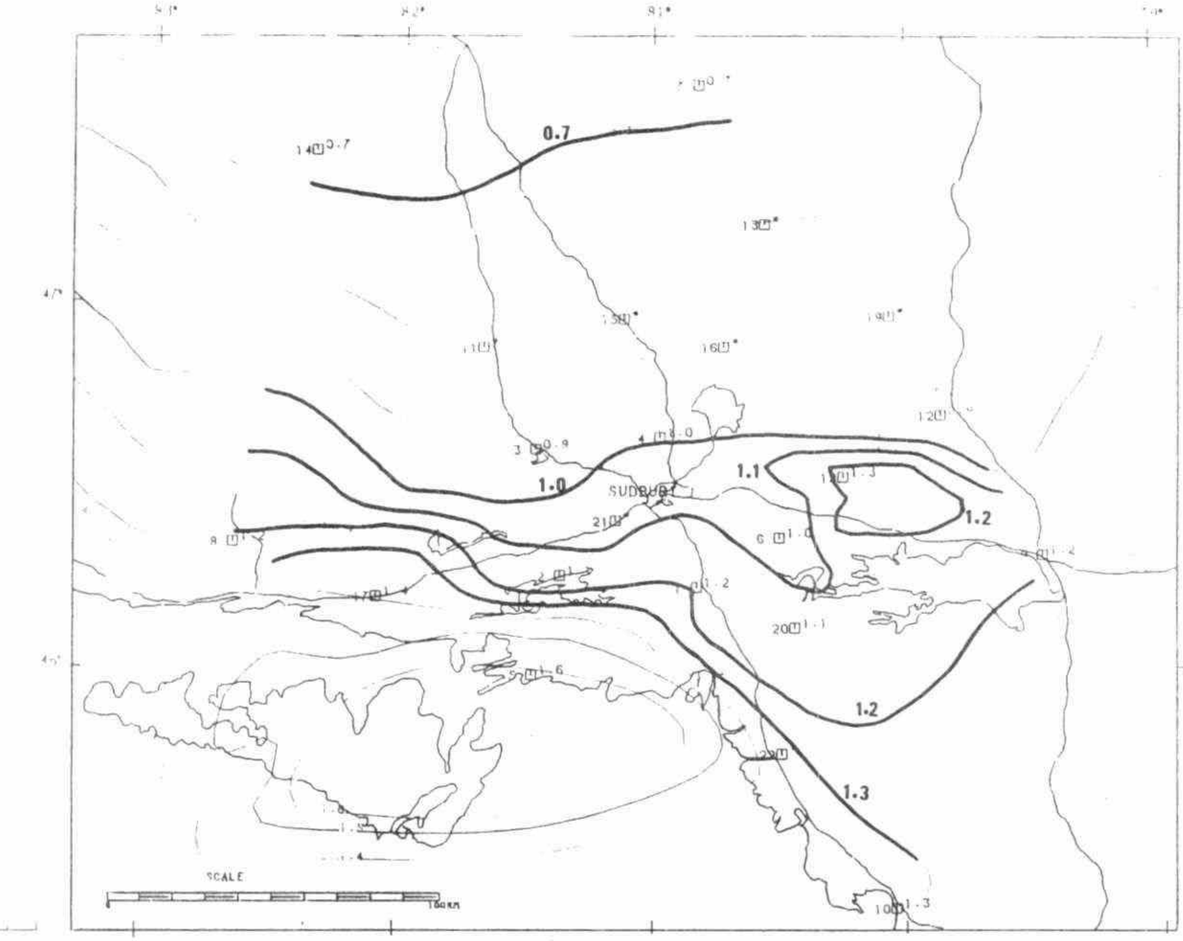


Figure 40a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF PB - JUN 78 TO MAY 79

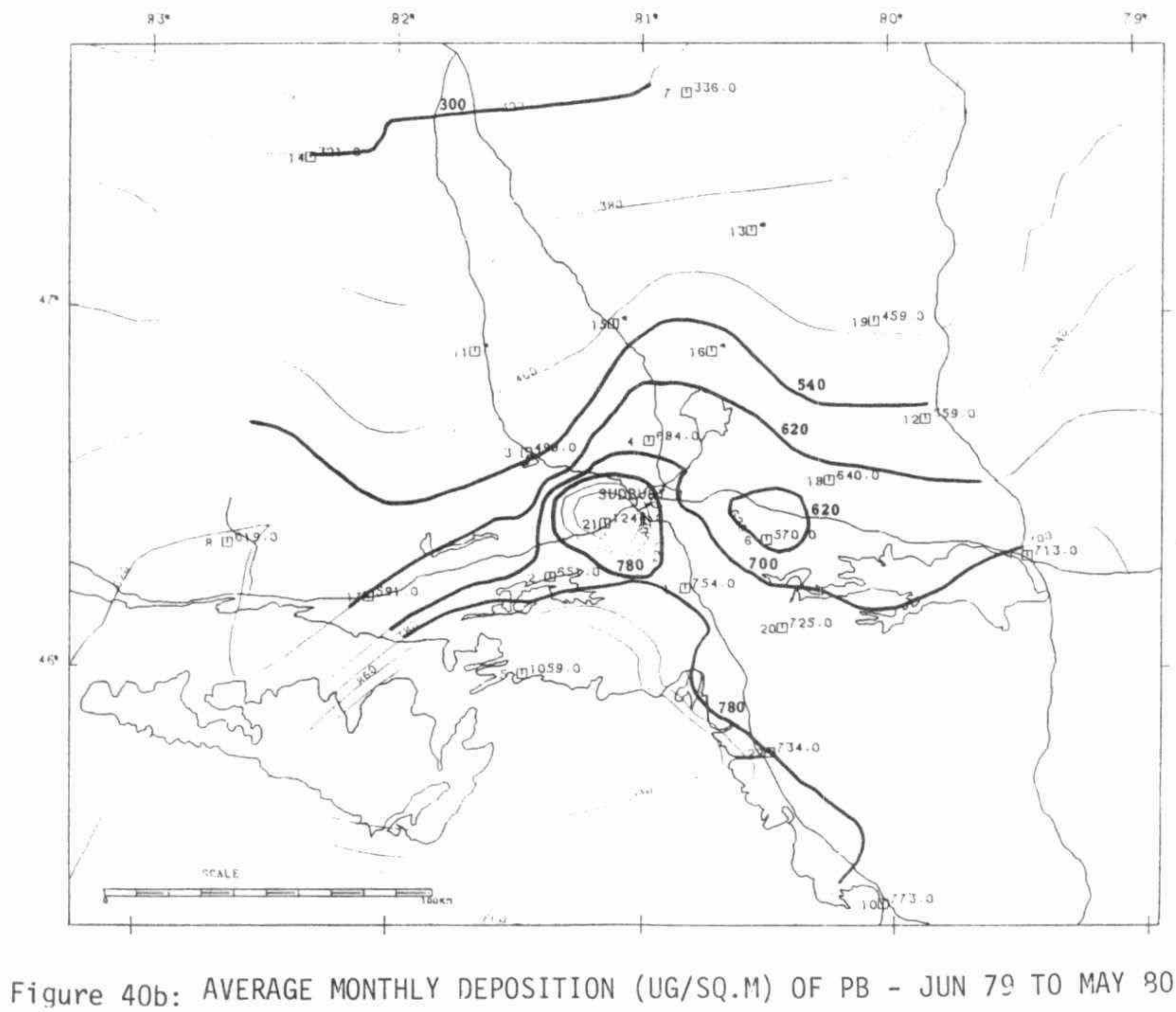


Figure 40b: AVERAGE MONTHLY DEPOSITION (UG/SQ.M) OF PB - JUN 79 TO MAY 80

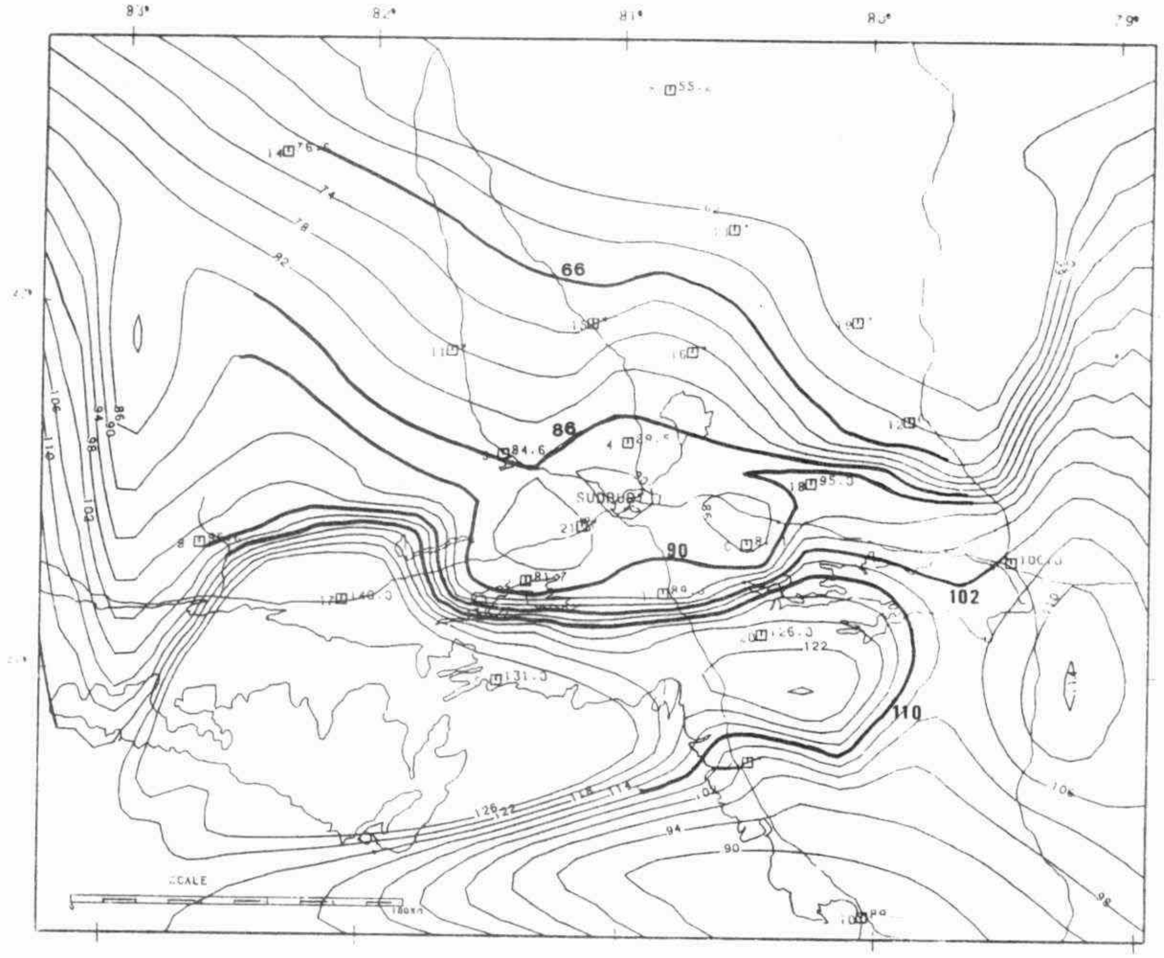


Figure 41a: AVERAGE MONTHLY DEPOSITION (10 UG/SQ.M) OF ZN - JUN 78 TO MAY 79

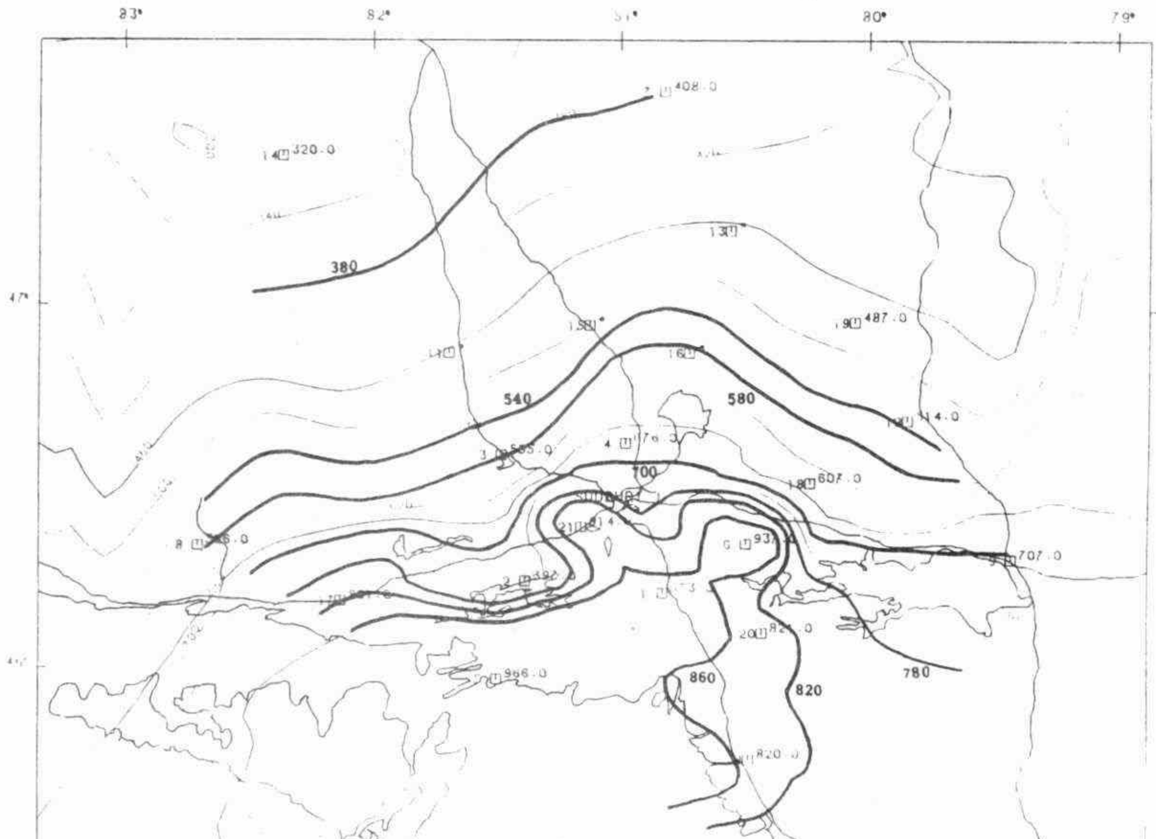


Figure 41b: AVERAGE MONTHLY DEPOSITION (UG/SQ.M) OF ZN - JUN 79 TO MAY 80

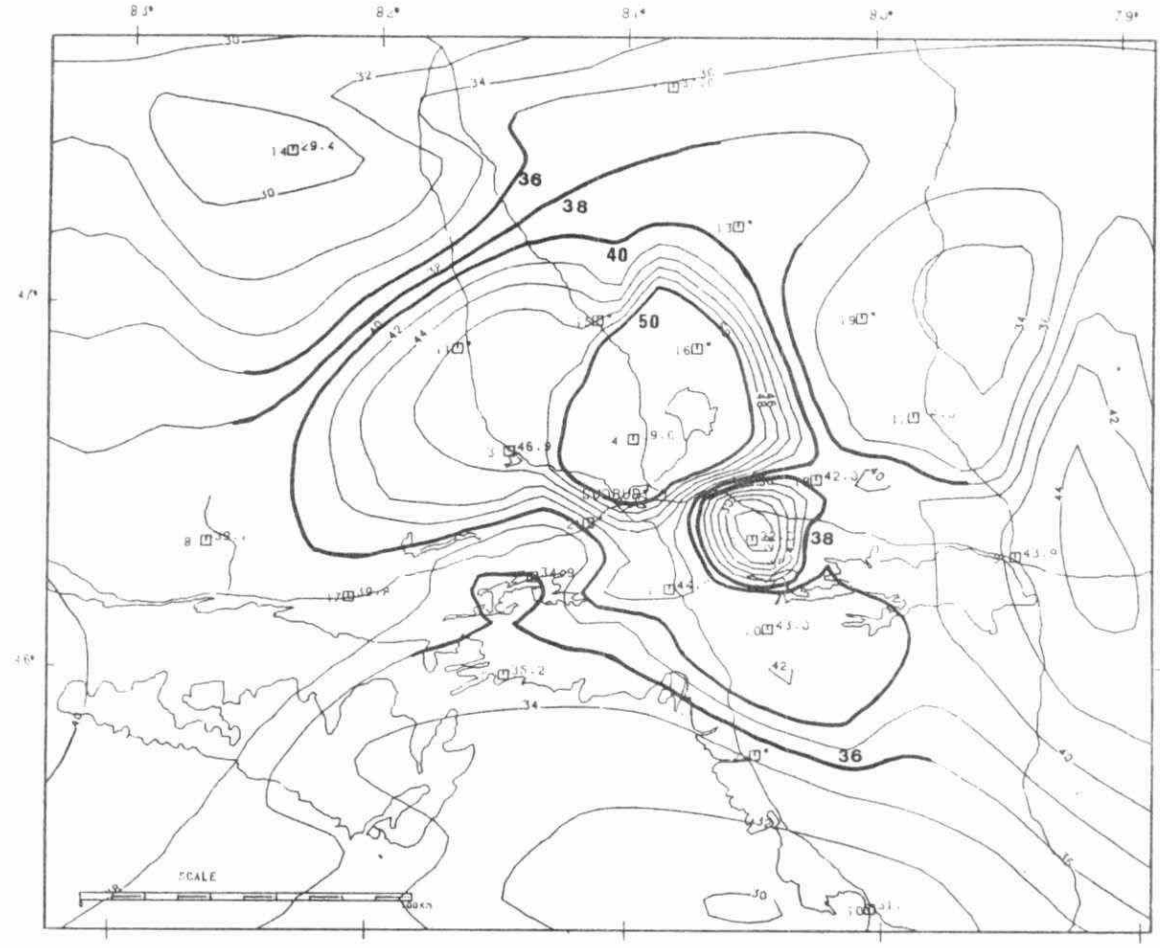


Figure 42a: AVERAGE MONTHLY DEPOSITION (UG/SQ.M) OF CR - JUN 78 TO MAY 79

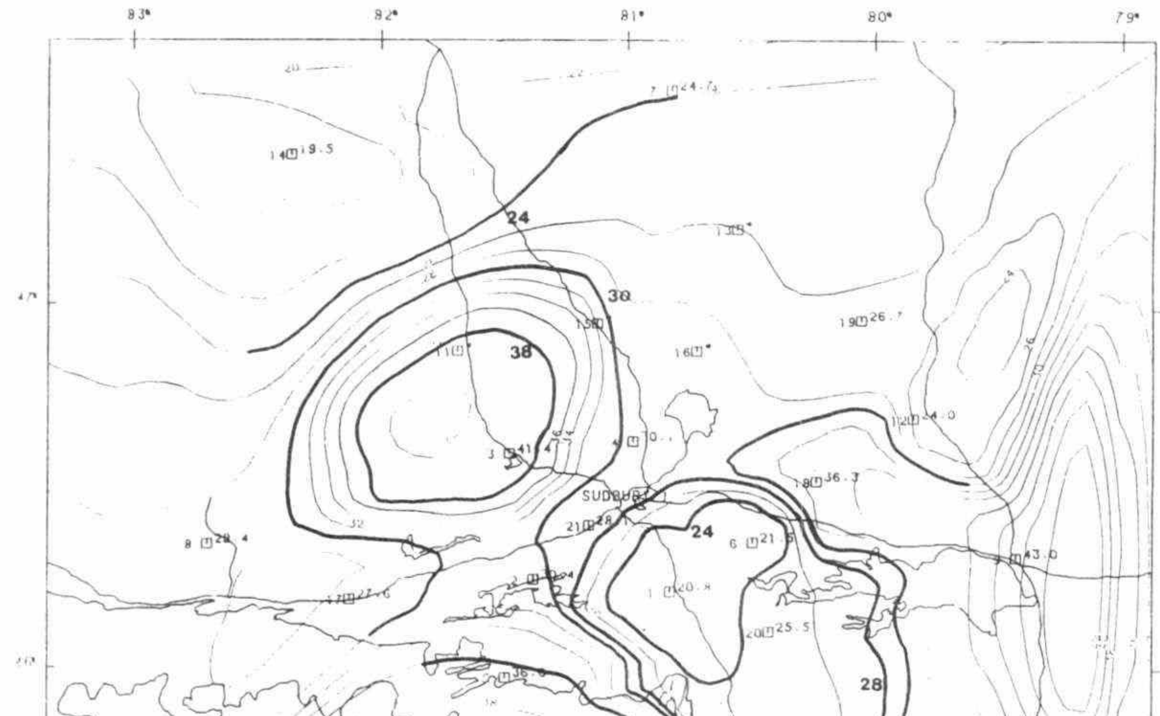


Figure 42b: AVERAGE MONTHLY DEPOSITION (UG/SQ.M) OF CR - JUN 79 TO MAY 80

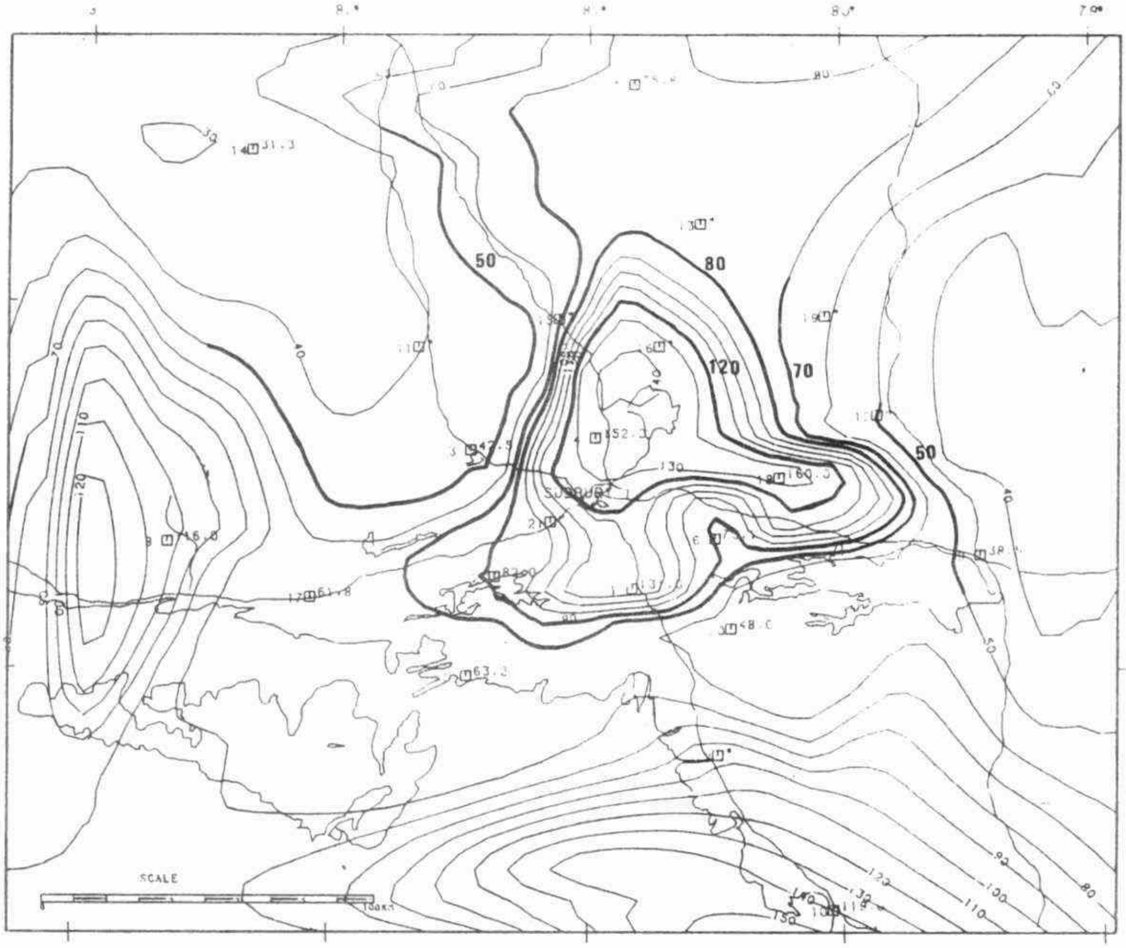


Figure 43a: AVERAGE MONTHLY DEPOSITION (UG/SQ.M) OF CE - JUN 78 TO MAY 79

Figure 43b: AVERAGE MONTHLY DEPOSITION (UG/SO.M) OF CD - JUN 79 TO MAY 80

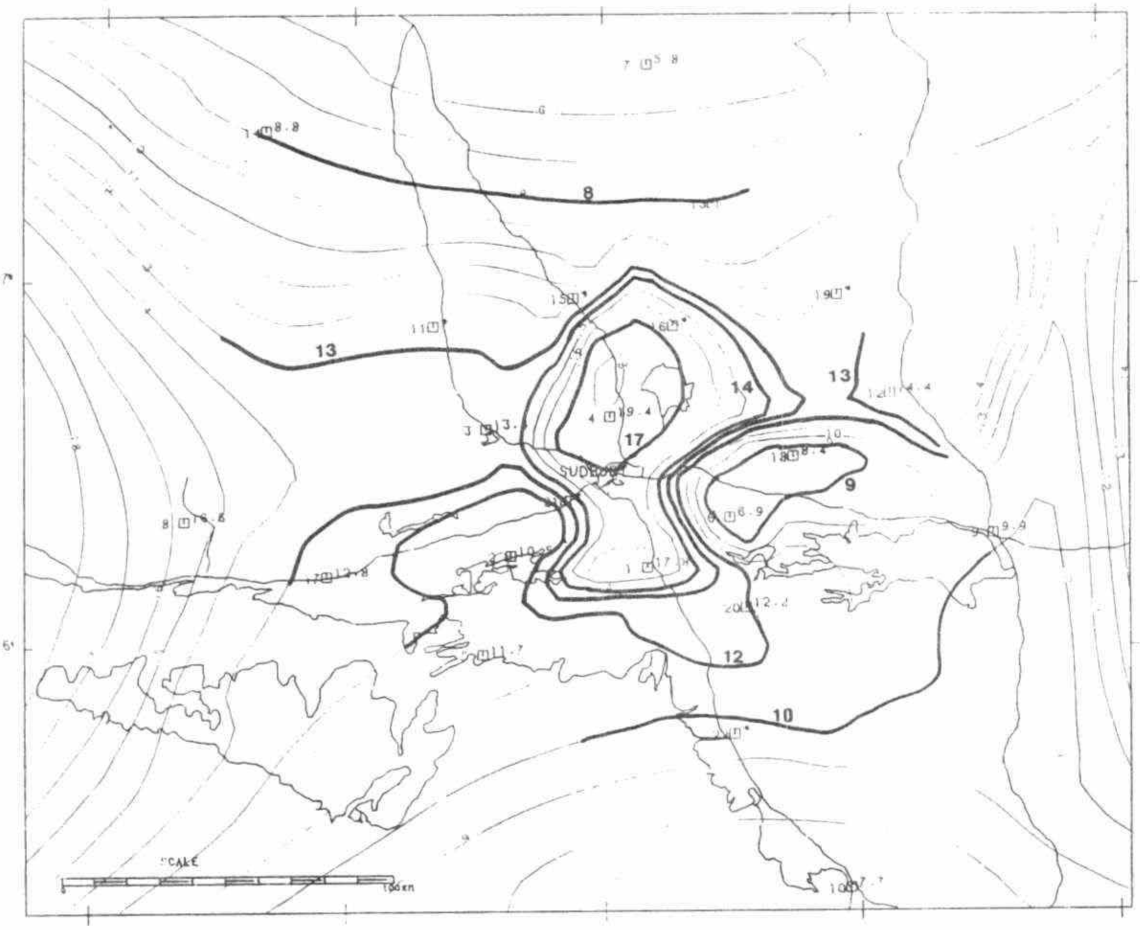


Figure 44a: AVERAGE MONTHLY DEPOSITION(MG/SQ.M) OF NA - JUN 78 TO MAY 79

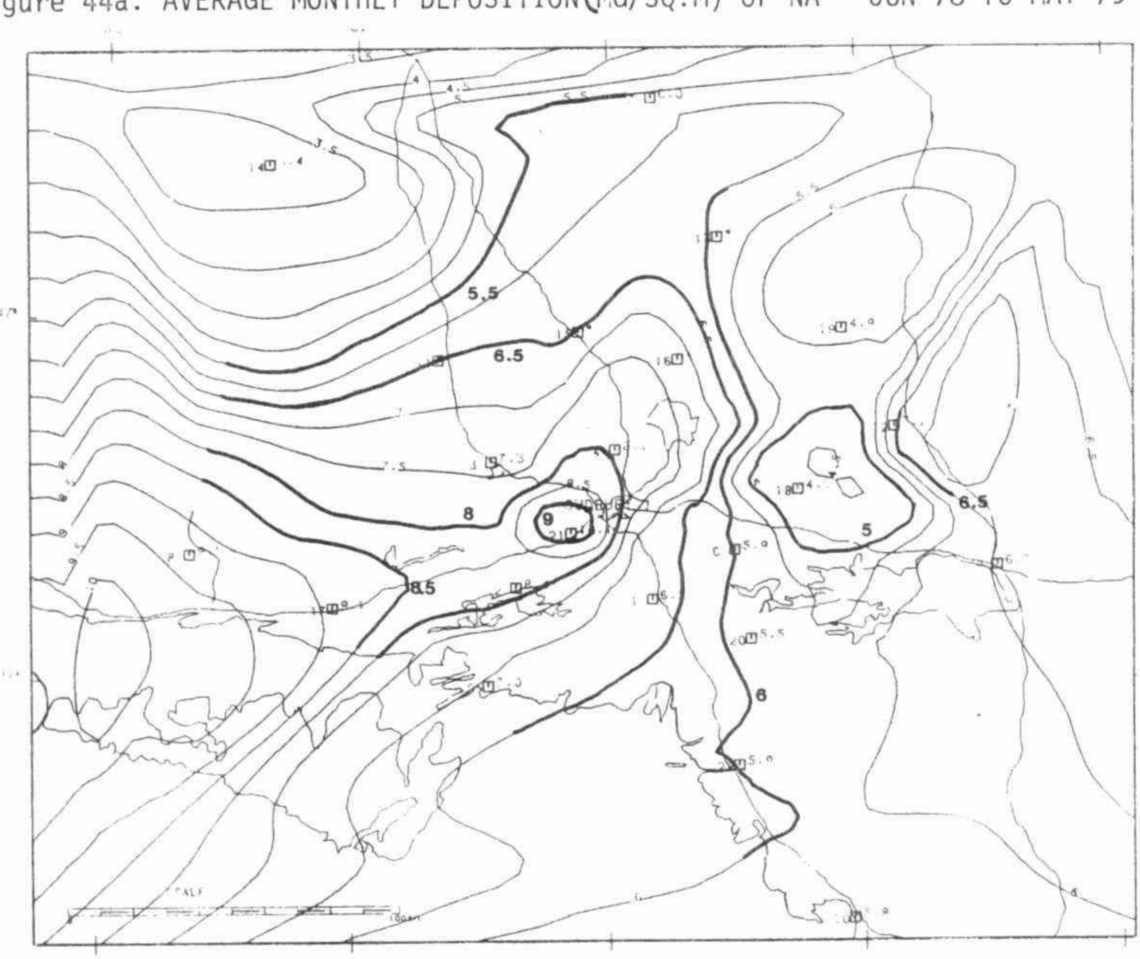


Figure 44b: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF NA - JUN 79 TO MAY 80

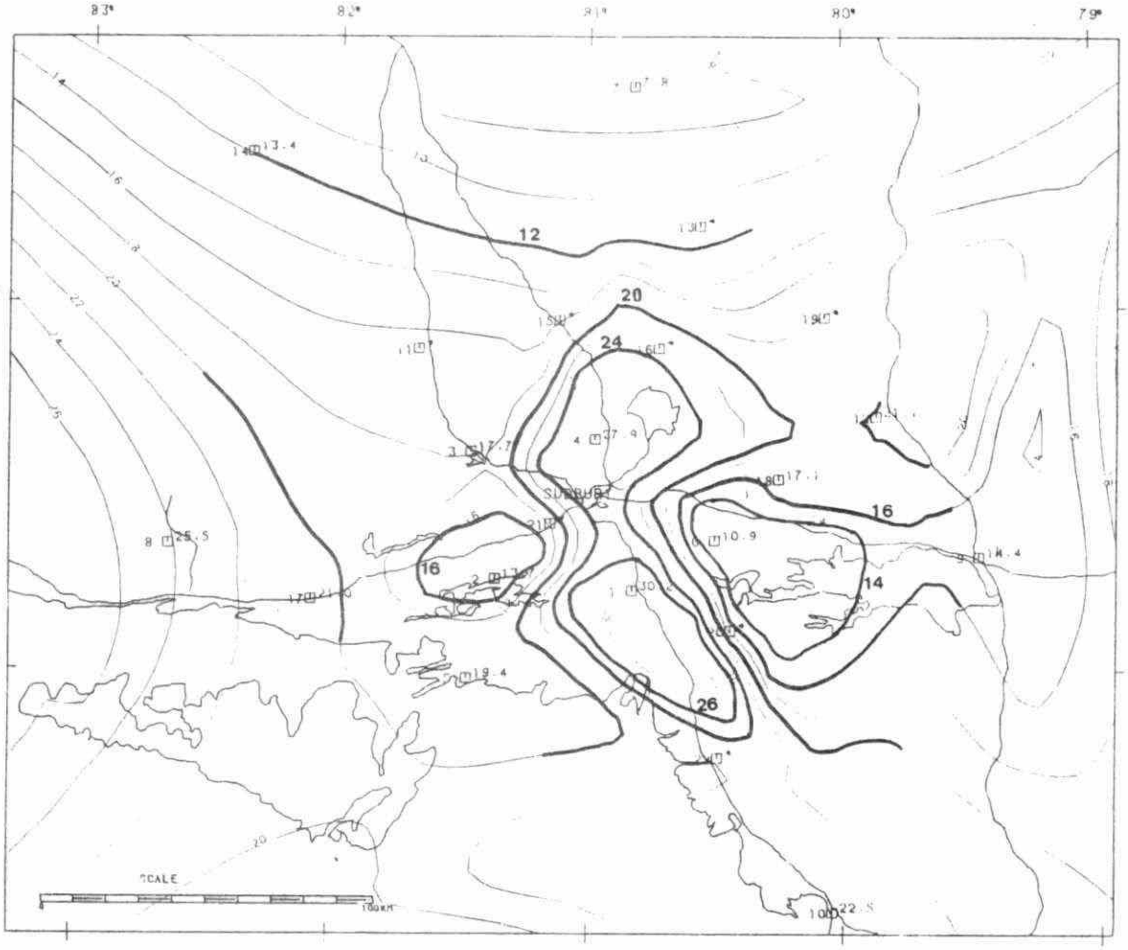


Figure 45a: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF CL - JUN 78 TO MAY 79

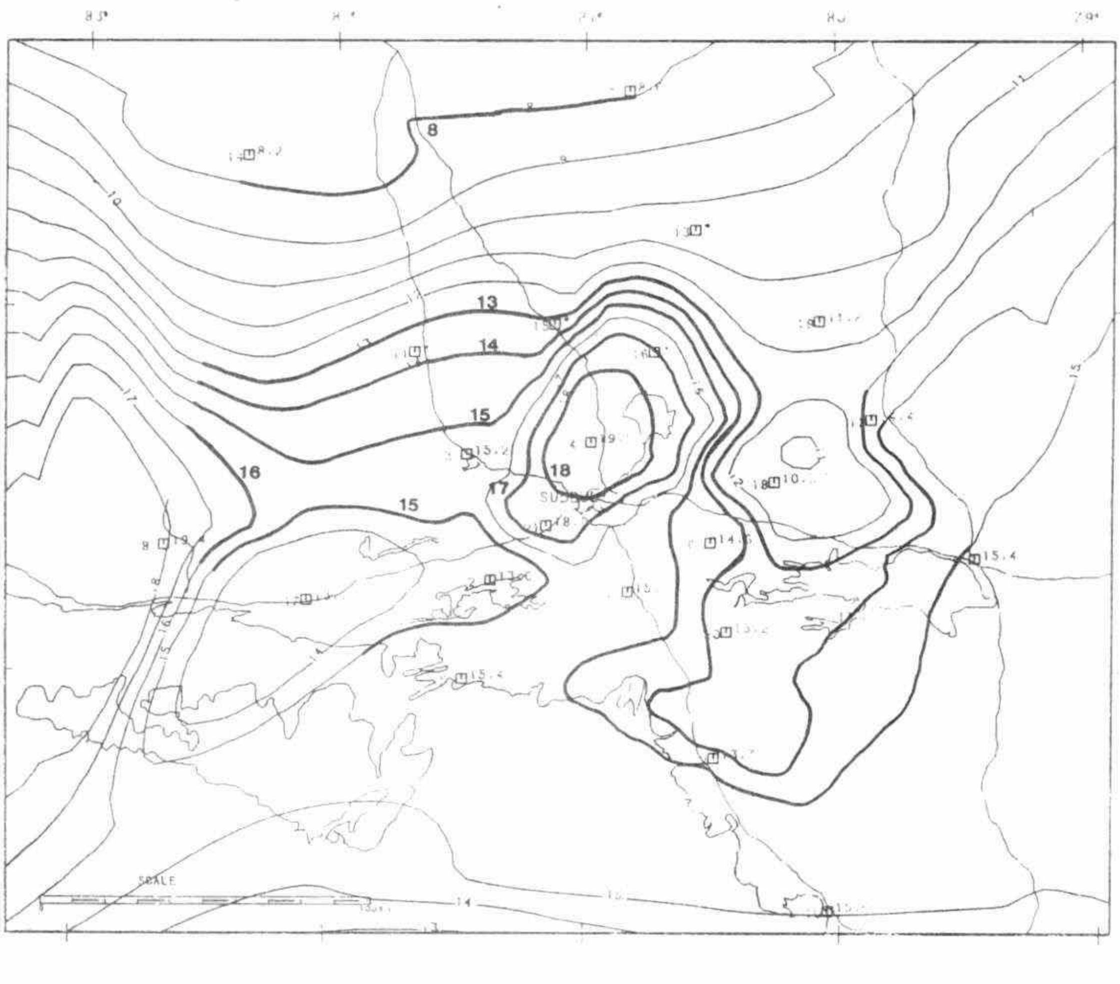


Figure 45b: AVERAGE MONTHLY DEPOSITION (MG/SQ.M) OF CL - JUN 79 TO MAY 80

APPENDIX 1

DESCRIPTION OF THE SES CUMULATIVE NETWORK

Twenty-two automatic wet-only deposition collectors were located within a 150 Km radius of Sudbury. The spatial distribution of the samplers within this area was determined using a two-step process. First, a theoretical grid of equilateral triangles was superimposed on a map of the area and each of the 19 triangle vertices was considered as an ideal sampler location. Then, a field inspection program was initiated to locate samplers as close as possible to the vertices. Limitations due to accessibility, power, personnel, and site characteristics resulted in significant deviations from the ideal design. Figure 1 illustrates the final network design and Table 1 summarizes each station's name and coordinates . The stations are further broken down in Table 2 into groups according to their radius from the INCO smelter in Sudbury.

The original design of the network called for 18 samplers. Of these, 10 were installed in late 1977 and 8 in mid-1978. Because the samplers required AC line power, they could not be installed in remote areas. This resulted in a paucity of samplers in the area to the north and northeast of Sudbury. To overcome this problem, 4 battery-operated samplers of a different design were installed in this area. Unfortunately, these samplers did not perform well and the number of samples obtained from them was quite limited.

In addition to the regular network operations, two special studies were designed into the Cumulative Network. At Burwash, two wet-only samplers were co-located within 5 metres of each other and were operated continuously throughout the study. This was done to provide a measure of sampling precision. Also, at Burwash, Windy Lake, Killarney and Noelville, bulk deposition samplers (similar to those used in the 1972 to 1976 Kramer Network) were co-located with

the wet-only samplers to provide a comparison between the two measurement methods.

A1.1 Instrumentation

The basic instrument used in the Cumulative Network was the Sangamo Type A Wet/Dry Deposition Collector. It consisted of a sensor for the detection of precipitation, a bucket for the collection of precipitation, a hood for covering the bucket during non-precipitating periods and a motor drive mechanism for moving the hood off the bucket when precipitation occurred. The bucket and motor unit were set within a stainless steel housing mounted on a 1.2 metre anodized aluminum stand-pipe. The instrument operated on 120 volt AC line power and is illustrated Figure 2.

The vessel for the collection of precipitation consisted of a black, high-density polythylene bucket 38.1 cm high, 21.0 cm O.D., and 19.7 cm I.D. with a collection area of 304 cm^2. A screw-on white polyethylene lid was provided with each bucket. Four buckets were dedicated to each sampler and were used in rotation - one in the sampler, one at the laboratory, one in transit and one at the SES field office.

Early in the field program, it was recognized that the polyethylene walls of the container selectively adsorbed Fe, Al and Cr from the collected precipitation. It was found that during laboratory analysis these materials could be desorbed using a nitric acid leach.

The standard Sangamo collector supplied by the manufacturer underwent several modifications throughout the course of the program. The first

modification was made by the Air Resources Branch prior to installation of the collectors in the field. It consisted of mounting a 3 mm thick silicone gasket on the underside of the moveable hood. This gasket was designed to provide a tight seal between the sample collection vessel and the hood--thereby minimizing evaporative losses and contamination by particulates (and gases) during dry periods. Extensive laboratory testing indicated that adsorption and desorption of materials from the gasket to the collected precipitation sample was negligible.

The other major modification occurred in April and May of 1978 when the original 10 Sangamo collectors were removed and modified to match the second generation of collectors. This modification consisted of changing the location of the precipitation sensor from the side of the collector housing to the end of an extender arm located roughly 0.5 m from the sampler body (see Figure 2). This was done to increase the detection capability of the sensor. No sampling time was lost while this modification was done because modified samplers were substituted for the old samplers when they were removed. After June 1978, all 18 Sangamo samplers used in the network were of the modified design. The balance of the modifications were relatively minor.

In addition to the 18 Sangamo collectors, 4 battery-powered units manufactured by Aerochem Metrics were used at remote locations (Halfway Lake, Florence Lake, Graveyard Lake and Chiniguchi Lake). These collectors operated on the same principle as the Sangamo but were of slightly different design. The major difference of note was the collection bucket which had an internal diameter of 28.7 cm corresponding to a collection area of 647 cm^2 roughly twice that of the Sangamo vessel.

The Aerochem Metric units were operated only during the summer months. Solar panels were used to recharge the storage batteries on a continuous basis during this time. A picture of the instrument is shown in Figure 3.

Each wet-only deposition collector was accompanied by a precipitation storage gauge. This consisted of a 1 meter black polyethylene standpipe (30.5 cm in diameter) which stored precipitation over a six month period. During the summer months, a small layer of oil was placed on top of the water to prevent evaporative losses. In the winter, the gauge was charged with ethylene-glycol to allow the precipitation to melt. This method was not totally satisfactory for eliminating freezing of the accumulated precipitation in the gauge. A photograph of the storage gauge is shown in Figure 4.

Six Fisher and Porter Recording Rain Gauges were also used in the Cumulative Network. Each consisted of a collection vessel, a weighing mechanism and a digital punch-tape recording system. Precipitation depth was recorded every 15 minutes on the punch tape which was, in turn, submitted every three to four months to the Atmospheric Environment Service for data translation. A photograph of a Fisher and Porter Gauge is shown in Figure 5.

A1.2 Network Operations

The operation of the Cumulative Network is described in four separate sections: site selection, sample handling and submission, chemical anlaysis and network performance.

A1.2.1 Site Selection

A specific set of site selection criteria was used to locate and approve sites for the installation of the wet deposition collectors. These criteria were developed to minimize interference and contamination of collected samples from site-specific sources. The criteria were:

1. The site should be located in an open area away from all obstacles, e.g. trees, building , towers. As general rule, the sampler should be at least 2.5H away from the nearest obstacle of height H.
2. The site should not be near cultivated fields, salt or sand piles, gravel pits, gardens, orchards, parking lots, airports, marshes, sewage lagoons, urban areas, smokestacks, or industrial activity.
3. The site should be accessible but not close to roads-especially dirt or gravel roads.
4. The ground cover should be grassy, with a minimum of sand and exposed rock nearby.
5. AC 115 volt power must be available.
6. The topography of the site should be representative of the general area. Sites on top of, or in the shadow of, large hills should be avoided.
7. The site should be safe and, if possible, manned.

Not all sites satisfied all of these criteria. The rugged and undeveloped nature of the Sudbury area required that some compromises be made at some sites. However, the quality of sites in the Cumulative Network was generally very high.

A1.2.2 Sample Handling and Submission

The cumulative wet deposition samples were collected at the end of each month ($\pm$ 3 days) by Sudbury Environmental Study field personnel. The total collection generally required two days with travel by vehicle and in the summer, by aircraft.

The sample handling procedures were as follows:

1. Upon arrival at the site, the wet deposition collector was tested for proper operation.
2. The hood was moved off the collection vessel and the instrument was turned off.
3. The collection vessel was lifted from the sampler and capped with a pre-cleaned lid.
4. If required, repairs were made to the sampler. It was then carefully washed with ethanol and distilled deionized water. Special care was given to cleaning the underside of the hood (the area exposed to the collected precipitation sample).
5. A clean bucket was placed in the collector; the cap was unscrewed and placed in a clean plastic bag. In the summer, a sheet of aluminum foil was placed around the outside of the bucket to reduce solar radiative heating of the bucket and its sample.
6. The sampler was turned on, checked for proper operation, and left in its normal operating mode.
7. The depth of precipitation collected in the precipitation storage gauge was measured and noted.

8. After all samples were collected, they were taken to the Sudbury Environmental Study field office where laboratory submission forms were filled out.
9. Within several days of collection, the samples were transported to the Laboratory Services Branch of the Ontario Ministry of the Environment for chemical analysis.

A.1.2.3 Chemical Analysis

After the samples were collected and returned to the field laboratory, a field pH measurement was made using a 50 ml aliquot (provided that sufficient volume of the sample was available for further chemical analysis). Samples were then shipped to the Laboratory Services Branch in Toronto in the polyethylene buckets for chemical analysis. The samples were not filtered prior to analysis. An aliquot was removed for the analyses of pH, acidity, SO_4, NO_3, NH_4, Ca, Na, K, Mg, Cl and F and the remainder of the sample was analysed for Fe, Ni, Cu, Pb, Zn, Al, Cr and Cd after spiking with 0.5 ml of 5% HNO_3. The empty containers were further leached with 1 litre of 5% HNO_3 and the leachate was analyzed for Fe, Al and Cr. Si and Br were also analyzed for initially but were dropped because most of the measured values were below detection limit.

The analysis methods used are summarized in Table 3 together with their corresponding detection limits.

A.1.2.4 Network Performance

It can be seen from Table 4 that the Sangamo collectors operated

very well with roughly 16% of the samples missing. The Aerochem Metric samplers, however, performed poorly with roughly 63% of the samples missing. This was due in part to the fact that the samplers were completely unattended for each month under quite variable weather conditions. In fact, the sampler at Halfway Lake provided no data whatsoever.

Table 4 also indicates that in the months of July, August and September of 1978, sampling was carried out semi-monthly. This was done because of shutdowns in the INCO and Falconbridge smelter operations and sampling was done in a manner reflecting source conditions.